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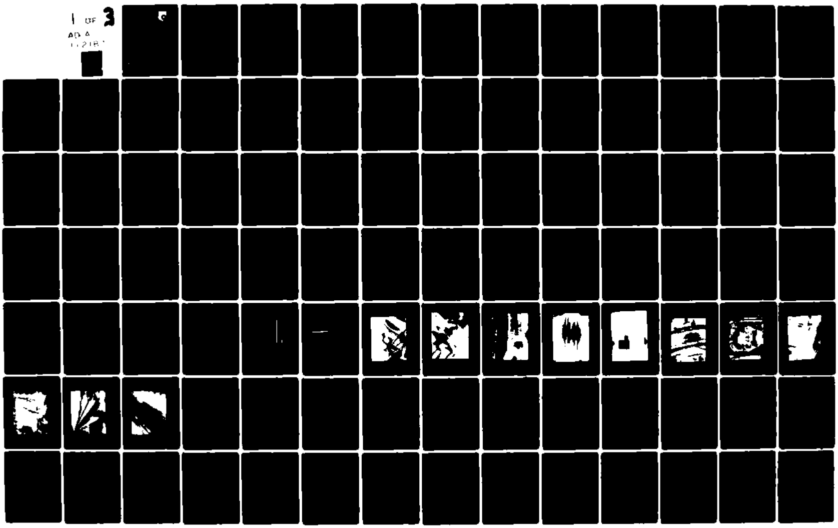

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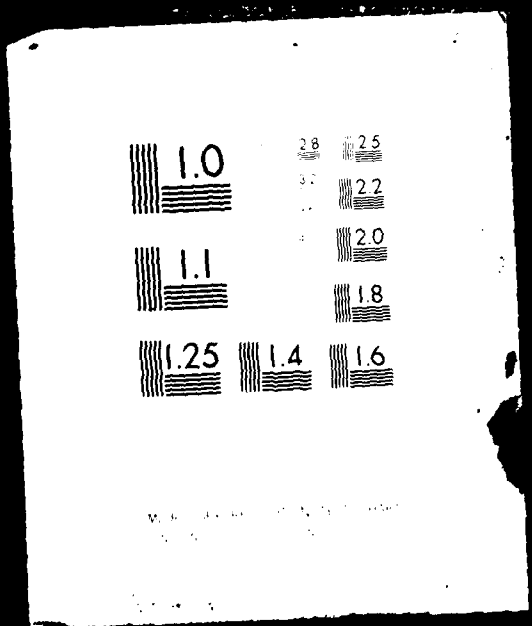

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WET TRACTION TESTS - MARCY SIPED TIRE

Paul C. Ulrich

Mechanical Branch
Vehicle Equipment Division

February 1982

Final Report For Period August 1977 - September 1979

Approved for public release; distribution unlimited.

FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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This technical report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes an in-house effort by USAF AFWAL/FIEM personnel in which a new method for siping aircraft tires was evaluated. The method, developed by Marcy Inc., promised improvements in wet surface traction without compromising tread wear or high speed tread integrity.

The purpose of this program was to laboratory test, track test, and evaluate the improvements in viscous hydroplaning or wet surface traction provided by the Marcy siped aircraft tire treads and to determine if this process compromised

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) the tread integrity of the tires.

The results of the high speed dynamometer tests indicated that the tread integrity of the F-4 and F-16 main gear tires were not adversely affected by the Marcy tread sipe configurations that were tested.

The results of the F-4 tire wet traction laboratory tests and the KC-135 tire track tests indicated significant improvements in lateral force, developed brake torque, and stopping performance for the 1/4 inch deep by 3/16 inch spacing Marcy siped tire tread configuration when compared to a standard (unsiped) tread design. This improvement in wet traction, however, was reduced to a negligible amount when the sipe depth is reduced by tire wear to depths less than 1/8 inch as demonstrated by the wet portland cement track tests.

None of the Marcy sipe configurations, however, prevented dynamic hydroplaning when the tires encountered standing water at high speeds during the track tests.

FOREWORD

This report describes an in-house effort conducted by personnel of the Mechanical Branch (FIEM), Vehicle Equipment Division (FIE), Flight Dynamics Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, under project number 2402, "Mechanical Systems for Advanced Military Flight Vehicles," task number 240201, "High Performance Landing Gear for Advanced Military Flight Vehicles," work unit number 24020118, "Tire Ground Performance Criteria." This report covers work performed during the period of August 1977 to September 1979, under the direction of the author, Paul C. Ulrich (AFWAL/FIEMA), project engineer. The report was released by the author in December 1980.

The author wishes to acknowledge the various suggestions received during this program from Aivars V. Petersons of the Flight Dynamics Laboratory and Dr. Howell K. Brewer of the Department of Transportation.

The contributions received from personnel of the Airport Technology Division, ACT-400, at the Federal Aviation Administration (FAA) Technical Center who conducted the track tests and personnel of the Naval Air Engineering Center (NAEC) at Lakehurst, New Jersey who provided the test track facility are greatly appreciated.

The author also acknowledges the assistance contributed by Juergen Mollnau (exchange engineer) of the Federal Republic of Germany, Ted Dull (co-op) student at the University of Cincinnati, J. L. Leiter, and A. R. Blazer of Systems Research Laboratories.

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SECTION I

INTRODUCTION

1. BACKGROUND

Aircraft adverse weather ground operations (wet or icy runways with high gusty cross winds) have been a primary concern since the introduction of jet aircraft as their landing speeds are usually well above the hydroplaning speed of their tires. In addition, with the continued improvement in flight instruments and instrument landing systems, more landings are attempted under adverse weather conditions. This increase in adverse weather ground operations coupled with the higher landing speeds of new aircraft has led to increases in adverse weather landing accidents. In order to reduce hydroplaning accidents, researchers have continually sought to improve the traction of aircraft tires during adverse weather ground operations.

Researchers have defined three types of hydroplaning; viscous hydroplaning (thin film lubrication), reverted rubber hydroplaning, and dynamic hydroplaning.

Viscous hydroplaning is defined as thin film lubrication (water and/or contaminants) between the tire and the runway causing a degradation in braking and steering capability. Viscous hydroplaning is normally associated with aircraft operation on damp, wet, or icy runways. This research effort deals with the evaluation of tread configurations which promise a reduction in viscous hydroplaning.

Dry reverted rubber hydroplaning is defined as tire skidding caused by reverted rubber build-up between the tire and the runway which can occur during rapid tire spin-up at the time of touchdown or during heavy braking (wheel lock-up). Changes in rubber compounding by the tire manufacturers is one known way of reducing dry reverted rubber hydroplaning. This type of hydroplaning was not considered in this research effort.

Dynamic hydroplaning is defined in two degrees or levels of hydroplaning. Partial dynamic hydroplaning is defined as a partial loss of the tire's contact (footprint) area due to a sufficient increase in the ground hydrodynamic pressure which is caused by a film of water being trapped between the tire and the runway. This loss in contact area causes a degradation in traction capabilities. Total dynamic hydroplaning is defined as a complete loss of contact between the tire and the runway as the ground hydrodynamic pressure has been increased sufficiently to support the entire wheel load and the tire rides on a layer of water of distinct thickness causing a complete loss of braking and steering capability. Past research has determined that the predominant parameters which affect dynamic hydroplaning are aircraft speed, tire inflation pressure, water depth, the runways surface texture, the tire contact area (footprint), and the tire's tread pattern. Subsequent research has also determined that as an aircraft's speed is increased, there exists a critical speed (dynamic hydroplaning speed), unique for each tire inflation pressure, in which the runway surface micro texture and the tire's tread pattern are no longer important in reducing dynamic hydroplaning. Total dynamic hydroplaning was not considered in this research effort as runway grooving is considered a much more effective means of reducing total dynamic hydroplaning than changes in tire tread patterns. Partial dynamic hydroplaning was considered during the flooded track tests at the Navy's Lakehurst facility.

NASA defined three levels of runway water depth in the joint USAF-NASA program, "Combat Traction" (Reference 1); damp, wet and flooded as determined by the NASA water depth gage. These were defined as:

damp - water depth less than 0.01 inch

wet - water depth between 0.01 inch and 0.10 inch

flooded - water depth greater than 0.10 inch

A comparison of the various water depths that were used in the Marcy siped tire traction program, the water depths used in previous traction tests on transverse groove (rain) tires at the NASA track, and the water depths used in actual aircraft traction tests on various runways in the combat traction tests, is shown in Figure 1.

The effects of runway texture on traction and hydroplaning have been studied by researchers in various ways. NASA has measured numerous runways and defined a typical operational runway in Reference 2 as having an average texture depth of the order of 201 μm (0.008 in) as determined by the grease sampling technique described in Reference 3. In Reference 4, roads and runways have also been classified in very general qualitative terms with respect to their macro and micro texture in four classes of surfaces as:

SURFACE	MACRO TEXTURE	MICRO TEXTURE
A	Rough	Harsh
B	Rough	Polished
C	Smooth	Harsh
D	Smooth	Polished

A quantitative measure of runway texture is the skid number as defined in Reference 5. Typical measured skid numbers of various wet concrete and asphalt pavements ranged from 25 to 65. In several cases it was observed that for any particular textured surface, the skid number decreased with increasing water depth until 0.01 inches of water depth was reached at which point the skid number remained constant regardless of additional increases in water depth. This fact undoubtedly led to NASA's criteria for distinguishing damp surfaces from wet surfaces.

A means of changing runway texture is that of adding runway transverse or longitudinal grooves. Runway grooving is recognized as the most effective way of reducing dynamic hydroplaning by providing adequate water drainage between the tire and the pavement; however, it requires a large initial capital investment with high recurring maintenance costs and has the detrimental side effects of increased tire wear and tire damage (chevron cutting).

The addition of a porous friction course over worn runways has been reported as being effective in reducing hydroplaning but this method has not been universally accepted.

A comparison of the texture depths of the various test surfaces used in the Marcy siped tire traction program, the test surfaces used in previous traction tests at the NASA track, and the test surfaces of actual runways is shown in Figure 2.

The effect of changing a tire's tread pattern to reduce hydroplaning has been studied many years with various small improvements being developed. Previous studies have shown that the most effective way of reducing hydroplaning through tread design is circumferential grooves of adequate cross sectional area to sufficiently drain the water trapped between the tire and the pavement. However, any increases in the number of grooves or increases in the width or depth of the grooves compromises tread wear. Consequently, the tire companies have traditionally established a tradeoff between tread life and the tire's hydroplaning tendencies.

Subsequent studies have also indicated that the benefits provided by runway grooving and circumferential tire tread grooving for reducing dynamic hydroplaning on flooded runways far exceed any benefits which could be achieved by other tread design changes, such as transverse tire grooving. Therefore, this program primarily addresses viscous hydroplaning with a cursory look at the phenomenon of dynamic hydroplaning.

In References 2, 6, and 7, it is reported that adding more circumferential grooves and/or transverse grooves in the tire tread is an effective way of improving tire traction and reducing aircraft stopping distances. This was demonstrated through track testing and actual aircraft tests on damp and wet runways. However, previous testing also determined that tread wear and tread integrity during high speed operation have been limiting factors in past tread alterations and, therefore, these factors must always be evaluated for new tread designs.

In August 1977, a different method of reducing viscous hydroplaning and improving the wet traction of tires was developed by Marcy Inc. This method, unlike previous transverse groove designs, did not remove tread material but rather sliced transverse cuts into the tire tread. A photograph of the Marcy Inc machine siping an F-4 main tire is shown in Figure 3. A close up of the helix sipe-cutting blade is shown in Figure 4, while a close up of an F-4 main tire with Marcy transverse cuts or sipes is shown in Figure 5. This process conceivably promises improvements in wet surface traction without compromising tread wear or high speed tread integrity. Therefore, an agreement was made between the Air Force and Marcy Inc in which the Air Force would provide and test F-4 main gear tires which had been siped by Marcy Inc in order that the Marcy siping process could be evaluated by the Air Force for improved wet surface tire traction and the tread integrity of the tires could be verified.

The tread integrity tests and laboratory wet surface traction tests were performed by Air Force, AFWAL/FIEM personnel at the Landing Gear Development Facility (LGDF), WPAFB, while the wet concrete track tests were performed by Federal Aviation Administration (FAA), National Aviation Facilities Experimental Center (NAFEC) personnel at the Naval Air Engineering Center (NAEC) Facility in Lakehurst, New Jersey.

Potentially, this siping process can provide a means to significantly improve aircraft safety and increase adverse weather operating capability when operating on damp or wet ungrooved runways.

2. OBJECTIVE

The objective of this program was to laboratory test, track test, and evaluate the improvements in viscous hydroplaning or wet surface traction (aircraft directional control and stopping capability) offered by the Marcy Inc tire tread siping process and to determine if this process compromised the tread integrity of the tire.

SECTION II

SUMMARY

1. Based on the results of the high speed tread integrity tests conducted on the LGDF 120 inch dynamometer, the Marcy tread siping process did not adversely affect the tread integrity of either the F-4 or F-16 main gear tires that were tested at sipe depths up to 9/32 inch deep for the F-4 tire and 7/32 inch deep for the F-16 tire.

2. During the flooded quasi-static lateral force and braking tests on the Tire Force Machine (TFM) aluminum (flat) surface, the Marcy siped tread F-4 tires showed large improvements in lateral force and developed brake torques over the standard tread F-4 tire. It is believed, however, that these improvements are much higher than can be expected for typical runways due to the extremely low textured aluminum surface and can only be correlated with aircraft operation on extremely icy or snow covered runways.

3. During the flooded quasi-static lateral force and braking tests on the TFM tungsten carbide (flat) surface, the Marcy siped tread F-4 tires showed significant improvements in lateral force over the standard tread F-4 tire. These results are considered more realistic since the texture of the tungsten surface is within the range of measured runway textures.

4. During the damp high speed lateral force tests on the steel (curved) surface dynamometer, the Marcy siped tread F-4 tire demonstrated significant improvements in lateral force over the standard tread F-4 tire at all test speeds and at all tire slip angles. This data relates to viscous hydroplaning and can be correlated with aircraft operation on damp runways or track tests on damp test surfaces since the estimated water depth achieved on the dynamometer flywheel surface was less than 0.002 inch at speeds greater than 80 mph and less than 0.01 inch for all test speeds. The amount of improved lateral force obtained during these tests is also considered somewhat high since the flywheel surface texture falls slightly below the range of typical runway textures.

5. During the damp high speed braking tests with the Mark III anti-skid on the steel (curved) surface dynamometer, the Marcy siped tread F-4 tire demonstrated significant improvements in deceleration rates, developed brake torques and stopping performance when compared to the unsiped tire. The trend for improvement in stopping performance provided by the Marcy sipe tire correlated with actual aircraft data obtained during previous F-4 rain (transverse groove) tire performance flight tests at Edwards AFB (Reference 7). The amount of demonstrated improvement, however, was much higher for the laboratory tests, presumably, due to the low surface texture of the steel flywheel.

6. The F-4 Marcy siped tread tire also demonstrated significant improvements over the standard tread tire in tire spin-up times on the damp flywheel surface during the high speed brake anti-skid stops.

7. During the high speed traction tests at the NAEC (Navy) test track, the Marcy siped (1/4 inch deep by 3/16 inch spacing) tread KC-135 main tire showed a significant increase in friction coefficient over the standard (unsiped) tread tire when tested on the damp (no measurable water depth) portland cement surface at all test speeds.

The improvement in friction coefficient demonstrated by the 1/8 inch deep by 3/16 inch spacing Marcy siped KC-135 main tire, however, was insignificant when compared to the standard tire during the wet track tests.

On portland cement track surfaces containing standing water (average water depth of 0.05, 0.10 and 0.15 inch), neither the 1/8 inch deep nor 1/4 inch deep siped tire prevented dynamic hydroplaning or showed an improvement in friction coefficient over the standard (unsiped) tire.

SECTION III

DESCRIPTION OF TEST TIRES

The tires used in TFM dynamometer brake stop tests, and the dynamometer tread integrity tests were F-4 main gear 30X11.5-14.5, 24 ply rating, type VIII aircraft tires. These tires were the standard three grooves (circumferential) design currently in the US Air Force inventory. The specified minimum mold skid depth of these tires is 0.26 inch per Reference 8. The Marcy sipe configurations tested with this size tire are listed in Table 1. A Marcy sipe configuration of 5/32 inch deep by 3/16 inch spacing is shown in Figure 6.

Additional dynamometer tread integrity tests were performed on siped F-16 main gear 25.5X8.0-14, 18 ply rating, aircraft tires for possible F-16 application. These tires were the standard three groove (circumferential) design currently in the US Air Force inventory. The specified minimum mold skid depth of these tires is 0.20 inch per Reference 9. The Marcy sipe configuration tested with this size tire is listed in Table 2 and shown in Figure 7.

The tires tested at the NAEC test facility located at the US Navy Lakehurst, New Jersey test track were KC-135 main gear 49X17, 26 ply rating, type VII aircraft tires. These tires were the standard four groove (circumferential) design currently in the US Air Force inventory. The specified minimum mold skid depth of these tires is 0.40 inch per Reference 6. The Marcy sipe configurations tested with this size tire are listed in Table 3 and the 4/32 inch deep by 3/16 inch spacing sipe configuration is shown in Figure 8. The F-4 main gear tire with the Marcy sipes was not track tested since the FAA test track fixture could not be readily adapted to accept a tire with a 30 inch outside diameter. In addition, the FAA was currently conducting wet traction tests on a commercial six groove 49X17/26 ply rating tire and their set up and fixturing was compatible with the Air Force four groove tire.

In order to eliminate errors caused by tire-to-tire variability when comparing unsiped tire to siped tire configurations, the unsiped tire was tested to completion, removed from test, siped, and then retested to identical test conditions. This procedure, however, was not used during the track tests at the Navy facility.

SECTION IV

TEST EQUIPMENT

The laboratory tire tests were conducted by AFWAL/FIEM personnel in the Flight Dynamics Laboratory (FDL) Landing Gear Development Facility using the flat surfaced TFM, the 192 inch conventional dynamometer and the 120 inch programmable dynamometer, while the track tests were conducted by FAA-NAFEC personnel and NAEC personnel at the NAEC test track facility in Lakehurst, New Jersey.

1. TIRE FORCE MACHINE (TFM)

The TFM was used for the quasi-static flooded flat surface traction cornering and braking tests. The force-measuring system consists of six load cells (3 vertical, 2 fore-aft and 1 lateral) instrumented to measure all six force-and-moment components developed by the tires. The machine is designed to permit low speed (0.17 mph) tests at yaw angles between ±20 degrees and any desired value of longitudinal slip. A photograph showing an F-4 sipe tire being set-up in the TFM is shown in Figure 9. Flooded traction tests of an F-4 siped tire are shown in Figure 10. The TFM testing was performed on a smooth aluminum surface with an average texture depth of 0.0004 inch and a tungsten carbide surface with an average texture depth of 0.004 inch as measured by the grease smear technique developed by NASA (Reference 3).

2. 192 INCH CONVENTIONAL DYNAMOMETER

The 192 inch dynamometer was used for the F-4 normal energy damp surface brake stops and the tire spin up tests. The flywheel had an average texture depth of 0.002 inch as measured per Reference 3.

3. 120 INCH PROGRAMMABLE DYNAMOMETER

The 120 inch dynamometer, incorporating a force measuring system similar to the TFM, has the capability of programmable yaw, camber, radial load, wheel velocity, wheel acceleration, and sink rate. The high speed tread integrity tests and the high speed cornering tests on a damp surface were performed on the 120 inch dynamometer. The measured texture depth of the flywheel was 0.002 inch as measured per Reference 3.

Descriptions and capabilities of the TFM, 192 inch, and 120 inch dynamometers are listed in the FDL Landing Gear Development Facility Brochure (Reference 10).

4. NAEC TEST TRACK FACILITY

Test track number 1 at the NAEC facility in Lakehurst, New Jersey was developed jointly by the FAA and the US Navy and it has the capability of simulating a jet transport tire-wheel assembly at touchdown and rollout. A 4000 lb steel yoke housed the tire-wheel assembly, applied the loading and braking to the wheel, and contained the instrumentation system which measured the loading, angular motion, and linear motion of the wheel. The dynamometer or steel yoke was an adaptation of a NASA design. The dynamometer and tire-wheel assembly shown in Figure 11 were contained in a 60,000 lbs dead load fixture. The dead load fixture was accelerated to speeds between 70 and 130 knots by four J-48 jet engines, each capable of 6000 lbs of thrust. The dead load fixture was arrested by a cable-fluid brake system at the recovery end of the mile long track.

The loading was applied to the wheel through two hydraulic cylinders activated by pressurized nitrogen. The vertical load applied in these tests was 39000 lbs.

The braking system was activated in a manner similar to the loading system. Vertical strain-gauged load links measured the vertical load applied to the wheel while horizontal strain-gauged load links measured the braking force between the tire and the surface tested.

The test bed surface shown in Figure 12 was a slab 200 feet long, 30 inches wide, and 5 inches thick consisting of Portland cement concrete of 5000 psi crushing strength, with a broomed surface finish shown in Figure 13. The average texture depth of the test surface as determined by the grease smear technique described in Reference 3, was 0.009 inch based on the average of eight grease smear measurements. The test surface was diked by rubber strips into five 40 foot test sections. Dimensional tolerances of the surface, for each section, were held to within ±0.16 inch from a horizontal plane. The first 40-foot section was kept dry to insure that all load transients had stabilized prior to entering the wet test sections. The second 40-foot section was damp but contained no measurable water depth. The three remaining 40 foot test sections contained average water depths of 0.05 inch, 0.10 inch and 0.15 inch, respectively.

SECTION V

TEST REQUIREMENTS AND PROCEDURES

1. STATIC TESTS

Tire Contact Area

F-4 Tire: The contact area prints (footprints) were obtained for the F-4 MLG, 30X11.5-14.5/24 PR tire when loaded against a flat surface and the 120 inch diameter dynamometer surface at three loads, 15000 lbs, 25000 lbs (rated), and 35000 lbs; and at two inflation pressures, 145 psig and 245 psig. The gross contact area of the tire footprints was measured and is defined as the total area of the print including the tread ribs and the spaces (tread grooves) between the tread ribs. The net area of the tire footprints was also measured and is defined as the summation of the individual tread rib areas where tread material contacts the test surface.

KC-135 Tire: The contact area prints (footprints) were obtained for the KC-135 MLG, 49X17/26 PR tire when loaded against a flat surface at two loads, 23760 lbs and 39600 lbs (rated), and at an inflation pressure of 170 psig (rated). The gross and net contact areas of the tire footprints were measured.

2. DYNAMIC TESTS

a. High Speed Tread Integrity Tests - 120 Inch Dynamometer

F-4 Tire: In order to check the tread integrity of the Marcy sipe configurations, F-4 main tires with various sipe depth and sipe spacing configurations were tested to the dynamic test conditions specified by USAF Drawing 62J4031, Exhibit "B" (Reference 11), which included 25 taxi takeoffs, 25 landing taxis, 25 inboard camber taxis, 25 outboard camber taxis, and 3 straight taxi rolls.

F-16 Tire: In order to check the tread integrity of a Marcy sipe configuration for F-16 application, an F-16 main tire, siped 7/32 inch deep and at a 3/16 inch spacing, was tested to the dynamic test conditions specified by the General Dynamics Drawing 16VL002A (Reference 9) which included 47 taxi takeoffs, 47 landing taxis, and 3 straight taxi rolls.

b. Quasi-Static Lateral Force and Braking Tests - TFM

F-4 Tire: Lateral force data was obtained for unsiped (standard) and siped F-4 tires on the dry and flooded (1/2 inch water) aluminum surface and on the dry and flooded (1/2 inch water) tungsten carbide surface of the TFM at a rated vertical load of 25000 lbs and at a rated inflation pressure of 243 psig and at tire slip angles of 3, 6, and 9 degrees with and without braking. The braked lateral force tests on the flooded TFM were performed by pre-determining the brake pressure required to produce maximum braking without incurring circumferential tire slip (rotational tire slip) for each set of test conditions. This brake pressure was then held constant for both the unsiped and siped tire configurations for each unique test condition.

c. High Speed Lateral Force Tests - 120 Inch Dynamometer

F-4 Tire: Lateral force data was obtained for unsiped (standard) and siped F-4 tires on the dry and damp flywheel surface at water flow rates of 1/2 gpm, 1 gpm, 2 gpm, 3 gpm, and 6 gpm, at constant flywheel speeds of 5 mph, 10 mph, 30 mph, and 60 mph, at a rated vertical load of 25000 lbs, at an inflation pressure of 268 psig, and at tire slip angles of 0°, 3°, 6°, and 9°. The 268 psig inflation pressure represents the test inflation pressure required for flywheel curvature correction per Reference 8. The various degrees of dampness were regulated with a valve, measured in gallons per minute (gpm) with an in line flow meter and applied evenly to the flywheel surface immediately in front of the tire/flywheel contact patch with a variable opening nozzle. Calculations were made to estimate the approximate water depths on the flywheel which were represented by the various flow rates as a function of the flywheel surface speed. Sample calculations are given in Appendix E. These results are plotted in Figure 14.

d. High Speed Braking Tests With Mark III Anti-Skid - 192 Inch Dynamometer

F-4 Tire: Normal energy brake stops per USAF Drawing 62J4031, Exhibit "A" (Reference 11), were conducted using unsiped (standard) and siped F-4 tires on a dry and damp flywheel surface at water flow rates of 1/2 gpm, 1 gpm, 2 gpm, 3 gpm, 4 gpm, and 7.5 gpm. The same valve, flow meter, and nozzle arrangemnt were used for the brake distance stops as were used and described for the high speed lateral force tests. The specific brake energy parameters and normal energy requirements are:

Kinetic Energy - 14,780,000 ft-lbs
Inertia Equivalent - 13,527 lbs
Initial Velocity - 181 mph
Deceleration Rate - 10.7 ft/sec^2
Braking Distance - 3,300 ft
Braking Time - 25 sec
Brake Torque - 56,000 in-lbs
Tire Load (Heavy GW) - 25,000 lbs
Tire Load (Light GW) - 16,000 lbs
Rolling Radius - 12.5 in

The normal energy brake stops were conducted using a complete F-4 brake hydraulic system mock-up with the actual brake system hardware which included a fully functioning Mark III anti-skid system, anti-skid box, anti-skid valves, wheel speed sensor, brake valves, restrictors, check valves, actual hydraulic line lengths, and the emergency brake system. Brake stops were conducted at two loads representing a heavy gross weight F-4 aircraft and a light gross weight F-4 and at two tire inflation pressures to evaluate tire inflation pressure effects.

e. High Speed Traction Tests - NAEC Test Track

The NAFEC and NAEC personnel were not able to readily adapt the test track fixtures to accept the F-4 MLG tire size. For the sake of expediency, it was decided to conduct track tests on the KC-135 MLG, 49X17/26 PR Marcy siped tires since this tire size fit into the existing equipment with minor fixturing changes. In addition, baseline traction data was available for this tire size from previous FAA traction studies.

The unsiped and siped tires were accelerated down the test track at constant tire speeds of 70 knots, 90 knots, 110 knots, and 130 knots, a tire pressure of 170 psig and at a vertical tire load of 39000 lbs. At the end of the test track, the 200 foot test section was divided into five 40 foot test sections. The system was launched with the tire in contact with the ground (concrete surface) and in a state of free roll supporting only the 4000 lbs weight of the test fixture for the full mile-length of the test track. Several hundred feet before the test bed was reached, the pusher cart was braked and separated from the test fixture with the test tire assembly. One hundred and fifty feet before the test bed was reached, the 39000 lb vertical load was applied to the test wheel. The tire/wheel assembly was braked approximately 30 feet before reaching the test bed. The fully loaded and braked aircraft tire/wheel assembly then entered the 200 foot test section at the desired speed. The tire encountered increasing water depths at each successive 40 foot test section. The first 40 foot test section was kept dry and used as baseline data. The second 40 foot test section was damp and contained water but no measurable depth. The last three 40 foot sections contained average water depths of 0.05 inch, 0.10 inch and 0.15 inch, respectively, as measured by the NASA water depth gauge (Reference 1).

Brake pressures were varied, depending on the traction capability of the tire-surface combination, in order to achieve maximum braking for each set of operating conditions. Maximum braking was not attempted on the dry surface.

A total of 64 tests were conducted in this series. The friction coefficient, the horizontal force between the tire and the concrete surface divided by the vertical load on the wheel, was measured over the entire length of the 200 foot test section.

SECTION VI

TEST RESULTS AND DISCUSSION

1. STATIC TESTS

Tire Contact Area

F-4 Tire: In order to establish baseline contact area data for the different size tires that were tested, contact area prints were obtained and measured for both the F-4 MLG tire and the KC-135 MLG tire. The contact area (footprints) data on the F-4 tire is tabulated in Table 4. The gross and net contact area vs normal load are plotted in Figure 15. The relationship between tire contact area, tire inflation pressure and dynamometer flywheel curvature is also shown in Figure 15. In Figure 16, the gross and net contact areas are plotted vs tire inflation pressure at three tire loads on both a flat and a curved surface. The gross and net contact areas of the F-4 tire are plotted vs percent tire deflection at a tire load of 25,000 pounds and at tire inflation pressure of 245 psig (Figure 17) and 145 psig (Figure 18) on both the flat and curved surfaces.

KC-135 Tire: The contact area prints (footprints) obtained on the KC-135 MLG tire were measured and the data is tabulated in Table 5. The gross and net contact areas are plotted vs normal load and percent deflection in Figures 19 and 20, respectively.

2. DYNAMIC TESTS

a. High Speed Tread Integrity Tests - 120 Inch Dynamometer

F-4 Tire: In order to determine if the Marcy sipe configurations adversely affect the tread integrity of the F-4 tire, five tires with various sipe configurations were subjected to the dynamic test conditions specified in the F-4 tire qualification specification. Three of the five tires successfully completed the 103 dynamic test cycles with only a slight or negligible amount of tread chunking visible at the test completion. The tread chunking is shown in Figure 6. The carcasses of the remaining two tires failed at depths below the tread sipes. None of the failures was considered to be caused by the Marcy siping process. The results of the tread integrity tests on the F-4 tires are tabulated in Table 6. The carcass failures of the F-4 tires were not considered a cause for alarm due to the severity of th- -4 qualification test and the Laboratory's historical failure data on the F-4 tire.

F-16 Tire: The tread integrity of an F-16 main tire with a 7/32 inch deep by 3/16 inch Marcy sipe was checked by subjecting the tire to the F-16 main tire qualification test. The tire, shown in Figure 7, successfully completed the 97 dynamic test cycles with a negligible amount of groove cracking and slight rib undercutting. None of the tread damage was considered caused by the Marcy siping process. The results of the tread integrity test on the F-16 tire are listed in Table 6.

b. Quasi-Static Lateral Force and Braking Tests - TFM

F-4 Tire: Quasi-static - flat surface - lateral tire force data was obtained for both unsiped and siped F-4 tires on the dry and flooded aluminum and tungsten carbide surfaces of the TFM. The test configurations and results are listed in Table 7. The 8/32 inch deep by 3/16 inch spacing sipe configuration demonstrated over 200 percent improvement in lateral force and a 30 percent improvement in developed brake torque for the flooded aluminum surface during maximum braking as shown in Figure 21. The 9/32 inch deep by 3/16 inch spacing siped configuration demonstrated improvements in lateral force for the flooded aluminum surface which ranged from 64 percent to 111 percent for unbraked runs and from 128 percent to 440 percent during maximum braking as shown in Figure 22. The 9/32 inch deep by 1/8 inch spacing siped configuration showed improvements in lateral force for the flooded aluminum surface which averaged about 78 percent for unbraked runs and 100 percent during maximum braking as indicated in Figure 23. The 5/32 inch deep by 3/16 inch spacing configuration showed an average improvement of 61 percent for unbraked runs on the flooded aluminum surface and an average improvement of 9 percent for unbraked runs on the flooded tungsten carbide surface as indicated in Figure 24. During dry runs on both the aluminum surface and the tungsten carbide surface, there was a slight increase in lateral force for the siped tire configuration as shown in Figure 25.

c. High Speed Lateral Force Tests - 120 Inch Dynamometer

F-4 Tire: High speed - curved surface - lateral tire force data was obtained for both unsiped and siped F-4 tires on the dry and damp steel surface of the 120 inch dynamometer. The test matrix and results are listed in Table 8. The 8/32 inch deep by 3/16 inch spacing siped configuration demonstrated significant improvements in lateral force over the unsiped tire for all speeds and tire slip angles during the high speed runs as shown in Figures 26 through 29 and listed in Table 8.

In an attempt to maintain a constant water depth on the flywheel for the various speed runs, flow measurements and calculations were made to generate a family of curves relating flywheel water depth vs dynamometer flywheel speeds for the various water flow rates. The results are shown in Figure 14 and listed in Table 8. An approximate water depth of 0.002 inch was maintained for the runs. In order to check the effect of slightly changing the water depth, a second set of 60 mph runs were made at a flow rate of 2 gpm (0.001 inch water depth). The percent improvement of the siped over the unsiped tire was reduced by approximately 10% when compared to the 6 gpm (0.002 inch water depth), 60 mph runs as shown in Figure 30. Attempts to significantly increase the water depth for the higher speed runs were halted due to the large flow rates and water volumes required.

During the dry high speed runs, there was an insignificant increase in lateral force at all tire slip angles as indicated in Table 8 and Figures 31 through 34.

d. High Speed Braking Tests with Mark III Anti-Skid - 192 Inch Dynamometer

F-4 Tire: Normal energy high speed brake stops were conducted on unsiped (standard) and siped F-4 30X11.5-14.5/24 PR tires on the dry and damp flywheel surface of the 192 inch dynamometer. The brake stops were conducted with a complete mock-up of the F-4 brake hydraulic and Mark III anti-skid systems which used actual F-4 brake system hardware. These tests were performed to study the interaction between the anti-skid system and the tread sipes which affects the traction at the tread/flywheel interface. Measurements and data were obtained to determine if the various tread sipe configurations provided increases in deceleration rates and brake torques resulting in decreased braked stop distances when compared to the unsiped tire. The brake stops were conducted at two different tire loads representing a heavy and light gross weight aircraft configuration and at two different tire inflation pressures. Most of the brake stops were conducted with the water applied before the tire was loaded against the flywheel, however, some were conducted with the water applied after fully loading the tire but prior to braking in order to determine what effect this might have on braking performance. The test sequence and test data for the dynamic anti-skid brake stops are tabulated in Tables 9 and 10.

The analog data for the brake stops on the tires code numbers 18-N (cycles 49 through 60), 20-N (cycles 61-66), 21-N (cycles 67 through 69 and 73 through 75), and 22-N (cycles 70 through 72 and 76 through 90) is shown in Figures C1 through C31 of Appendix C. Actual tire spin down or tire slip data was recorded on channel 2 (test wheel speed) while the anti-skid action or brake pressure and brake torque response was recorded on data channels 3 and 4. Analog plots of flywheel speed vs stopping distance comparing the unsiped and siped tire at each water flow rate for the above cycles is shown in Figures D1 through D15 of Appendix D.

The 8/32 inch deep siped tires (18-N, 20-N, and 22-N) and the 5/32 inch deep siped tire (21-N) demonstrated significant improvements in damp surface traction for the heavy gross weight aircraft condition at applied water flow rates greater than 1/2 gpm by developing greater brake torques which resulted in higher deceleration rates and much shorter brake stop distances than the unsiped tires as shown in Figures 35, 36, 37, and 38 and tabulated in Table 11. The results of these tests did not indicate a significant difference in traction performance on the damp surface between the two sipe depths (8/32 inch vs 5/32 inch).

The 8/32 inch deep siped tire (18-N) also demonstrated significant improvements in damp surface traction for the light gross weight aircraft conditions and at the reduced tire inflation pressure conditions at applied water flow rates greater than 1/2 gpm as shown in Figure 39 and Table 12.

In the preceding tests, the water was applied to the flywheel prior to loading the tire on the flywheel surface. The water was sprayed on the flywheel by means of the variable opening nozzle shown in Figure 40.

The analog data for the brake stops on the tire code number 1-R-2 (cycles 96 through 115) is shown in Figures C32 through C51 of Appendix C. Analog plots of flywheel speed vs stopping distance comparing the unsiped and siped tire, code number 1-R-2, are shown in Figures D16 through D24 of Appendix D.

The 7/32 inch deep siped tire (1-R-2) demonstrated significant improvements in damp surface traction over the unsiped tire for the light gross weight aircraft conditions (Table 13) both in the case in which water was applied to the flywheel before the tire was landed (Figure 41) and the case in which water was applied after the tire had landed with full load but prior to brake application (Figure 42). In case I, water applied before the tire landed, the unsiped tire failed to fully spin up and incurred total hydroplaning or total tire spin down during the 2 gpm brake stop (Figure C34). During two case I, 3 gpm, brake stops, the unsiped tire failed to fully spin up and incurred total hydroplaning (Figures C35 and C36). In case II, water applied after the tire landed, the unsiped tire fully spun up to the flywheel speed after landing on the dry flywheel but started immediately to spin down after water application and incurred partial hydroplaning during the 2 gpm stop (Figure C39) and total hydroplaning during the 3 gpm stop (Figure C40).

During case I and case II brake anti-skid stops, the 7/32 inch siped tire (1-R-2) did not incur total tire spin down or total hydroplaning at water flow rates of 1/2, 1, 2, 3, 4, and 7.5 gpm as shown in Figures C41 through C50. The application of the water to the flywheel at a flow rate of 4 gpm during a brake anti-skid stop is shown in Figure 43. The flywheel and tire had decelerated from 181 mph to 40 mph when this photograph was taken.

In Figure 44, the test wheel/tire speed is compared for the unsiped and siped configuration of the tire code number 18-N when tested to the heavy gross weight aircraft conditions for water flow rates of 1/2, 1, and 2 gpm. It is interesting to note the increased traction of the siped tire during initial tire spin up as the unsiped tire took longer than the siped tire to spin up to the synchronous flywheel speed. This difference in initial tire spin-up is even more prevalent in the light gross weight aircraft test runs as shown in Figure 45.

In Figures 46 and 47, a large difference is noted between the case I (water before tire load) and case II (water after tire load) tire spin ups. During the case I tests, the unsiped tire was unable to spin up to the synchronous flywheel speed at the high water flow rates while the siped tire was able to spin up to the flywheel speed (Figure 46). During the case II tests, both the unsiped and siped tire immediately reached the flywheel synchronous speed (Figure 47) since the surface was dry. As far as braking performance (decreased stop distance) was concerned, it did not appear to make much difference whether the water was applied before (case I) or after (case II) the tire was landed for either the unsiped or siped tire. Analog plots of flywheel speed vs stopping distance comparing case I and case II stops are shown in Figures D25 through D28 for the unsiped tire and Figures D29 through D32 for the siped tire. A comparison of the tire spin up of the 3 gpm brake stops for the unsiped and siped tires for case I and case II is shown in Figures 48 and 49.

Analog plots of flywheel speed vs stopping distance for case I and case II test runs at the various water flow rates are shown in Figures D33 and D34 for the unsiped tire and Figures D35 and D36 for the siped tire.

Brake anti-skid stops were conducted on a dry flywheel surface on the tires code numbers 22-N and 1-R-2 in order to establish baseline (dry surface) data. The analog data is shown in Figures C31 and C51. During the dry stop on 22-N (Figure C31), it was interesting to note the torque peaking which occurred in the middle of the braked run. Torque peaking which normally occurs at the end of a stop is thought to be caused by excessive localized non-uniform heating in the brake friction surfaces which results in rapid change in the friction coefficients of the rubbing surfaces and a rapid increase in the developed brake torques which in turn can cause the tire to spin down or skid. However, since the anti-skid system was operative, it cycled preventing a complete tire/wheel lock up as shown in cycle 90 (Figure C31). The tire/wheel speed, brake pressure, and brake torque data for the two dry stops are compared in Figure 50.

e. High Speed Traction Tests - NAEC Test Track

KC-135 Tire: High speed damp, wet, and flooded track tests were conducted at the NAEC facility by NAFEC and NAEC personnel on braked standard tread (unsiped) and siped 49X17/26 PR KC-135 main gear tires to evaluate the traction capability of a siped tire when tested on wet portland cement at various water depths and test speeds. The NAFEC test results at the NAEC facility are reported on in Reference 12. These results of the wet track tests are replotted in Figures 51 through 58. In Figures 51 through 53, the friction coefficient vs speed is plotted at the various water depths for the standard (unsiped) tire, the 1/4 inch deep by 3/16 inch spacing siped tire and the 1/8 inch deep by 3/16 inch spacing siped tire, respectively. Friction coefficient vs water depth is plotted in Figure 54 and the siped and unsiped tires are compared.

Friction coefficient vs speed is plotted for the siped and unsiped tires for the damp, 0.05, 0.10, and 0.15 inch test conditions in Figures 55 through 58, respectively.

During the damp condition (no measurable water depth) track tests, the 1/4 inch deep siped tire produced a significant increase in friction coefficient over the standard tread tire while the 1/8 inch deep siped tire showed only a slight improvement in friction coefficient over the standard tire (Figure 55).

During the track tests on surfaces containing standing water (average water depths of 0.05, 0.10 and 0.15 inch), neither siped tread tire showed a significant increase in friction coefficient over the standard tread tire and in most cases produced less traction (Figures 56, 57, and 58).

SECTION VII

CONCLUSIONS

1. The Marcy tread siping process does not appear to adversely affect the tread integrity of the F-4 or the F-16 main gear tires if the sipe depths and sipe spacing is constrained to those configurations tested.

2. The 1/4 inch deep by 3/16 inch spacing Marcy siped tread configuration reduced viscous hydroplaning and demonstrated significant improvements over the standard (unsiped) tread tire in lateral force, in developed brake torque and in stopping performance during laboratory tests and improved the friction coefficient during track tests.

3. The improvement in traction, however, is negligible on the wet portland cement surface when the sipe depth is reduced by tire wear to depths less than 1/8 inch. The Marcy siping machine, however, does allow for resiping a tire if sufficient tread material exists.

4. None of the Marcy sipe configurations prevented dynamic hydroplaning or demonstrated traction improvements during the track tests when the tire encountered standing water.

5. Since tread wear effects and chevron cutting effects can not be evaluated for the Marcy sipes through laboratory or track tests, these effects must still be evaluated before the overall payoffs can be determined.

SECTION VIII

RECOMMENDATIONS

The testing to date indicates that the Marcy 1/4 inch deep by 3/16 inch spacing siped tread configuration reduces viscous hydroplaning and offers significant improvements in friction coefficient, lateral force, developed brake torque, and stopping performance when encountering damp or wet ungrooved runway surfaces without adversely affecting the tread integrity of the tire. Since this demonstrated improvement can only be verified through aircraft tests on damp or wet runways, it is recommended that this effort be followed by flight demonstration tests.

Also, the US Navy has recently shown considerable interest in the Marcy siped tire based on the results of the Air Force wet traction tests, therefore, it is recommended that a joint US Air Force, US Navy flight test program be pursued in order to share the flight test costs. During these aircraft tests, additional questions such as what effects tread siping has on tread wear and chevron cutting can be addressed.

APPENDIX A

TABLES

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TABLE 1

F-4 MLG, 30X11.5-14.5/24 PR TIRE,
MARCY TREAD SIPE CONFIGURATIONS

TIRE CODE NR	SIPE DEPTH (IN)	SIPE SPACING (IN)	TYPE TEST
1-N	5/32	3/16	Tread Integrity - Dynamometer
6-N	9/32	1/8	" " "
8-N	5/32	1/8	" " "
11-N	5/32	3/16	" " "
12-N	5/32	3/16	" " "
3-N	8/32	3/16	Quasi-Static Cornering - TFM
5-N	9/32	3/16	" " " "
6-N	9/32	1/8	" " " "
11-N	5/32	3/16	" " " "
18-N	8/32	3/16	Brake Distance - Dynamometer
20-N	8/32	3/16	" " "
21-N	5/32	3/16	" " "
22-N	8/32	3/16	" " "
1-R-2	7/32	3/16	" " "
24-N	8/32	3/16	High Speed Cornering - Dynamometer

TABLE 2

F-16 MLG, 25.5X8.0-14/18 PR TIRE,
MARCY TREAD SIPE CONFIGURATION

TIRE CODE NR	SIPE DEPTH (IN)	SIPE SPACING (IN)	TYPE TEST
1-N	7/32	3/16	Tread Integrity - Dynamometer

TABLE 3

KC-135 MLG, 49X17/26 PR TIRE,
MARCY TREAD SIPE CONFIGURATIONS

TIRE CODE NR	SIPE DEPTH (IN)	SIPE SPACING (IN)	TYPE TEST
1-N	4/32	3/16	Traction Tests - Test Track
2-N	8/32	3/16	" " " "

TABLE 4

TIRE CONTACT AREA DATA,
F-4 MLG 30X11.5-14.5/24 PR TIRE

FLAT SURFACE:

LOAD (LBS)	INFLATION PRES (PSIG)	LENGTH (IN)	WIDTH (IN)	GROSS AREA (IN^2)	NET AREA (IN^2)	DEFLECTION %
15000	245	9.5	7.8	67	51	21
25000	245	12.4	8.8	98	82	32
35000	245	15.1	9.5	130	118	43
15000	145	11.8	8.4	92	72	30
25000	145	15.8	10.0	141	117	48
35000	145	18.4	11.2	183	156	62

CURVED SURFACE (120 INCH DIAMETER FLYWHEEL):

LOAD (LBS)	INFLATION PRES (PSIG)	LENGTH (IN)	WIDTH (IN)	GROSS AREA (IN^2)	NET AREA (IN^2)	DELFECTION %
15000	245	8.3	8.0	60	44	23
25000	245	10.6	8.9	88	78	36
35000	245	13.0	9.9	119	103	49
15000	145	10.4	8.7	83	68	33
25000	145	13.9	10.1	130	112	56
35000	145	15.9	11.6	166	140	69

TABLE 5

TIRE CONTACT AREA DATA
KC-135 MLG, 49X17/26 PR TIRE

FLAT SURFACE:

LOAD (LBS)	INFLATION PRES (PSIG)	LENGTH (IN)	WIDTH (IN)	GROSS AREA (IN^2)	NET AREA (IN^2)	DEFLECTION %
23,760	170	17.4	12.0	165	135	21
39,600	170	21.5	13.5	247	202	30

TABLE 6

HIGH SPEED TREAD INTEGRITY TEST DATA - 120 INCH DYNAMOMETER

TIRE CODE NR	SIPE DEPTH (IN)	SIPE SPACING (IN)	TAXI TAKEOFF (CYC)	LANDING TAXI (CYC)	INBOARD CAMBER (CYC)	OUTBOARD CAMBER (CYC)	TAXI ROLL (CYC)	REMARKS
F-4 TIRE:								
1-N	5/32	3/16	25	25	25	25	1	Carcass Failure (Blowout)
6-N	9/32	1/8	25	25	25	25	3	Successfully Completed Test
8-N	5/32	1/8	18					Carcass Failure (Blowout)
11-N	5/32	3/16	25	25	25	25	3	Successfully Completed Test
12-N	5/32	3/16	25	25	25	25	3	Successfully Completed Test
F-16 TIRE:								
1-N	7/32	3/16	47	47	--	--	3	Successfully Completed Test

TABLE 7

QUASI-STATIC LATERAL FORCE TEST MATRIX - TFM
TIRE LOAD (25000 LBS), TIRE INFLATION (243 PSI)

F-4 TIRE:

TIRE CODE NR	SIPE DEPTH (IN)	SIPE SPACING (IN)	BRAKING	TYPE SURFACE	SURFACE TEXTURE DEPTH (IN)	SURFACE CONDITION	LATERAL FORCE PERCENT IMPROVEMENT (%) @ FOLLOWING TIRE SLIP ANGLES 3°	6°	9°
3-N	Unsiped	--	Max	Aluminum	0.0004	½" water	Baseline	-	-
3-N	8/32	3/16	Max	"	"	"	200	204	264
5-N	Unsiped	--	None	"	"	"	Baseline	-	-
5-N	9/32	3/16	"	"	"	"	64	100	111
5-N	Unsiped	--	Max	"	"	"	Baseline	-	-
5-N	9/32	3/16	"	"	"	"	128	225	440
6-N	Unsiped	--	None	"	"	"	Baseline	-	-
6-N	9/32	1/8	"	"	"	"	75	80	78
6-N	Unsiped	--	Max	"	"	"	Baseline	-	-
6-N	9/32	1/8	Max	"	"	"	89	90	120
11-N	Unsiped	--	None	"	"	Dry	Baseline	-	-
11-N	5/32	3/16	"	"	"	Dry	11	6	1
11-N	Unsiped	--	"	"	"	½" water	Baseline	-	-
11-N	5/32	3/16	"	"	"	½" water	36	71	76
11-N	Unsiped	--	"	Tungsten Carbide	0.004	Dry	Baseline	-	-
11-N	5/32	3/16	"	" "	"	Dry	9	3	7
11-N	Unsiped	--	"	" "	"	½" water	Baseline	-	-
11-N	5/32	3/16	"	" "	"	½" water	20	6	2

TABLE 8

HIGH SPEED LATERAL FORCE TEST MATRIX - 120 INCH DYNAMOMETER
TIRE CODE NUMBER 24-N, SIPED 8/32 INCH DEEP BY 3/16 INCH SPACING,
TIRE LOAD (25,000) LB, TIRE INFLATION (268 PSIG)
CURVED SMOOTH STEEL SURFACE - AVERAGE TEXTURE DEPTH (0.002 IN)

FLYWHEEL SPEED (MPH)	TREAD TYPE	SURFACE CONDITION	WATER FLOW RATE (GPM)	APPROX WATER DEPTH (IN)	LATERAL FORCE PERCENT IMPROVEMENT (%) @ FOLLOWING TIRE SLIP ANGLES		
					3°	6°	9°
5	Unsiped	Dry	-	-	Baseline	-	-
5	Siped	Dry	-	-	0	0	3
10	Unsiped	Dry	-	-	Baseline	-	-
10	Siped	Dry	-	-	0	0	5
30	Unsiped	Dry	-	-	Baseline	-	-
30	Siped	Dry	-	-	0	0	3
60	Unsiped	Dry	-	-	Baseline	-	-
60	Siped	Dry	-	-	0	0	4
5	Unsiped	Damp	½	0.002	Baseline	-	-
5	Siped	Damp	½	0.002	6	5	3
10	Unsiped	Damp	1	0.002	Baseline	-	-
10	Siped	Damp	1	0.002	27	10	5
30	Unsiped	Damp	3	0.002	Baseline	-	-
30	Siped	Damp	3	0.002	23	16	11
60	Unsiped	Damp	6	0.002	Baseline	-	-
60	Siped	Damp	6	0.002	37	37	40
60	Unsiped	Damp	2	0.001	Baseline	-	-
60	Siped	Damp	2	0.001	28	30	25

TABLE 9

BRAKE STOP DATA,
30X11.5-14.5/24 PR UNSIPED VS SIPED TIRE

CYC NR	CODE NR	LOAD LBS	PRES (PSIG)	INITIAL SPEED (MPH)	FINAL SPEED (MPH)	FLOW RATE (GPM)	DECEL (ft/sec^2)	BRAKE TORQUE (in-lbs)	BRAKE DISTANCE (ft)	TREAD CONFIG
49	18-N	25000	245	180	57	½	6.6	39300	4752	Unsiped
50	18-N	25000	245	180	57	1	3.8	23580	8255	Unsiped
51	18-N	25000	245	180	57	2	2.6	13755	12065	Unsiped
52	18-N	16000	145	180	57	½	4.8	28820	6535	Unsiped
53	18-N	16000	145	180	74	1	2.4	15720	12071	Unsiped
54	18-N	16000	145	180	136	2	1.4	1965	10687	Unsiped
55	18-N	25000	245	180	57	½	8.1	53710	3873	Siped 8/32"
56	18-N	25000	245	180	57	1	5.6	35370	5601	Siped 8/32"
57	18-N	25000	245	180	57	2	3.8	19650	8255	Siped 8/32"
58	18-N	16000	145	180	57	½	4.8	34060	6535	Siped 8/32"
59	18-N	16000	145	180	57	1	3.5	24890	8962	Siped 8/32"
60	18-N	16000	145	180	99	2	1.9	9170	12799	Siped 8/32"
61	20-N	25000	245	180	57	½	7.8	62225	4022	Unsiped
62	20-N	25000	245	180	57	1	3.7	23580	8478	Unsiped
63	20-N	25000	245	180	113	2	1.7	5895	12426	Unsiped
64	20-N	25000	245	180	57	½	7.8	59605	4022	Siped 8/32"
65	20-N	25000	245	180	57	1	6.5	41920	4826	Siped 8/32"
66	20-N	25000	245	180	57	2	5.1	29475	6151	Siped 8/32"
67	21-N	25000	245	180	57	½	8.1	55020	3873	Unsiped
68	21-N	25000	245	180	57	1	4.7	34715	6674	Unsiped
69	21-N	25000	245	180	68	2	2.4	11790	12453	Unsiped
70	22-N	25000	245	180	57	½	7.5	51090	4182	Unsiped
71	22-N	25000	245	180	57	1	4.2	29475	7469	Unsiped
72	22-N	25000	245	180	57	2	2.7	12445	11618	Unsiped
73	21-N	25000	245	180	57	½	8.1	52400	3873	Siped 5/32"
74	21-N	25000	245	180	57	1	7.0	41920	4481	Siped 5/32"
75	21-N	25000	245	180	57	2	5.1	26200	6151	Siped 5/32"
76	22-N	25000	245	180	57	½	7.0	50435	4481	Siped 8/32"
77	22-N	25000	245	180	57	1	4.9	34715	6402	Siped 8/32"
78	22-N	25000	245	180	57	2	4.0	23580	7842	Siped 8/32"
90	22-N	16000	245	180	57	DRY	12.6	79910	2807	Siped 8/32"

TABLE 10

BRAKE STOP DATA
30X11.5-14.5/24 PR UNSIPED VS SIPED TIRE,
TIRE CODE NUMBER 1-R-2

CYC NR	CODE NR	LOAD LBS	PRES (PSIG)	INITIAL SPEED (MPH)	FINAL SPEED (MPH)	FLOW RATE (GMP)	DECEL (ft/sec^2)	BRAKE TORQUE (in-lbs)	BRAKE DISTANCE (ft)	TREAD CONFIG
96	1-R-2	16000	245	180	79	½	3.5	62880	8042	Unsiped
97	1-R-2	16000	245	180	102	1	1.9	14410	12457	Unsiped
98	1-R-2	16000	245	180	147	2	0.9	3930	12902	Unsiped
99	1-R-2	16000	245	180	-	3	-	1310	-	Unsiped
100	1-R-2	16000	245	180	-	3	-	1310	-	Unsiped
101	1-R-2	16000	245	180	70	½*	4.9	76635	6039	Unsiped
102	1-R-2	16000	245	180	127	1*	1.4	16375	12159	Unsiped
103	1-R-2	16000	245	180	150	2*	0.9	-	11837	Unsiped
104	1-R-2	16000	245	180	156	3*	0.9	-	9641	Unsiped
105	1-R-2	16000	245	180	57	½*	8.5	91700	3690	Siped 7/32"
106	1-R-2	16000	245	180	70	1*	2.5	34715	11837	Siped 7/32"
107	1-R-2	16000	245	180	142	2*	1.1	2620	11756	Siped 7/32"
108	1-R-2	16000	245	180	142	3*	1.0	2620	12660	Siped 7/32"
109	1-R-2	16000	245	180	57	½	9.6	83840	3267	Siped 7/32"
110	1-R-2	16000	245	180	60	1	2.6	31440	12012	Siped 7/32"
111	1-R-2	16000	245	180	136	2	1.3	2620	11249	Siped 7/32"
112	1-R-2	16000	245	180	142	3	1.2	2620	11350	Siped 7/32"
113	1-R-2	16000	245	180	142	4	1.2	1965	11350	Siped 7/32"
114	1-R-2	16000	245	180	153	7½	1.3	1965	7558	Siped 7/32"
115	1-R-2	16000	245	180	57	DRY	13.5	87770	2324	Siped 7/32"

*Water applied to flywheel after tire was landed and at full load. All other test cycles, the water was applied before tire was landed.

TABLE 11

BRAKE STOP COMPARISON DATA,
30X11.5-14.5/24 PR UNSIPED VS SIPED TIRE,
25,000 LBS LOAD, 245 PSIG PRESSURE
WATER APPLIED BEFORE TIRE LANDS

TIRE CODE NUMBER 18-N: Siped 8/32 inch deep by 3/16 inch spacing

Flow Rate (GMP)	½	½	IMPROVEMENT %	1	1	IMPROVEMENT %	2	2	IMPROVEMENT %
Tread Design	Unsiped	Siped		Unsiped	Siped		Unsiped	Siped	
Decel (ft/sec^2)	6.6	8.1	23	3.8	5.6	47	2.6	3.8	46
Torque (in-lbs)	34,300	53,710	57	23,580	35,370	50	13,755	19,650	43
Distance (ft)*	4,752	3,873	18	8,255	5,601	32	12,065	8,255	32

TIRE CODE NUMBER 20-N: Siped 8/32 inch deep by 3/16 inch spacing

Flow Rate (GPM)	½	½	IMPROVEMENT %	1	1	IMPROVEMENT %	2	2	IMPROVEMENT %
Tread Design	Unsiped	Siped		Unsiped	Siped		Unsiped	Siped	
Decel (ft/sec^2)	7.8	7.8	-	3.7	6.5	76	1.7	5.1	200
Torque (in-lbs)	62,225	59,605	-5	23,580	41,920	78	5,895	29,475	400
Distance (ft)*	4,022	4,022	-	2,478	4,826	95	18,452	6,151	67

TIRE CODE NUMBER 21-N: Siped 5/32 inch deep by 3/16 inch spacing

Flow Rate (GPM)	½	½	IMPROVEMENT %	1	1	IMPROVEMENT %	2	2	IMPROVEMENT %
Tread Design	Unsiped	Siped		Unsiped	Siped		Unsiped	Siped	
Decel (ft/sec^2)	8.1	8.1	-	4.7	7.0	49	2.4	5.1	113
Torque (in-lbs)	55,020	52,400	-5	34,715	41,920	21	11,790	26,200	122
Distance (ft)*	3,873	3,873	-	6,674	4,481	33	13,070	6,151	53

TIRE CODE NUMBER 22-N: Siped 8/32 inch deep by 3/16 inch spacing

Flow Rate (GPM)	½	½	IMPROVEMENT %	1	1	IMPROVEMENT %	2	2	IMPROVEMENT %
Tread Design	Unsiped	Siped		Unsiped	Siped		Unsiped	Siped	
Decel (ft/sec^2)	7.5	7.0	-7	4.2	4.9	5	2.7	4.0	48
Torque (in-lbs)	51,090	50,432	-1	29,475	34,715	18	12,445	23,580	89
Distance (ft)*	4,182	4,481	-7	7,469	6,402	15	11,618	7,842	33

*Distances listed are calculated values based on measured deceleration rates for entire speed range of 180 mph to 57 mph in order to make valid comparisons.

TABLE 12

BRAKE STOP COMPARISON DATA,
30X11.5-14.5/24 PR UNSIPED VS SIPED TIRE,
16,000 LBS LOAD, 145 PSIG PRESSURE,
WATER APPLIED BEFORE TIRE LANDS

TIRE CODE NUMBER 18-N: Siped 8/32 inch deep by 3/16 inch spacing

Flow Rate (GPM)	½	½	IMPROVEMENT %	1	1	IMPROVEMENT %	2	2	IMPROVEMENT %
Tread Design	Unsiped	Siped		Unsiped	Siped		Unsiped	Siped	
Decel (ft/sec^2)	4.8	4.8	-	2.4	3.5	46	1.4	1.9	36
Torque (in-lbs)	28,820	34,060	18	15,720	24,890	58	1,965	9,170	367
Distance (ft)*	6,535	6,535	-	13,070	8,962	31	22,406	16,509	26

*Distances listed are calculated values based on measured deceleration rates for entire speed range of 180 mph to 57 mph in order to make valid comparisons.

TABLE 13

BRAKE STOP COMPARISON DATA,
30X11.5-14.5/24 PR UNSIPED VS SIPED TIRE,
16,000 LBS LOAD, 245 PSIG PRESSURE,
TIRE CODE NUMBER 1-R-2,
SIPED 7/32 INCH DEEP BY 3/16 INCH SPACING

WATER APPLIED BEFORE TIRE LANDS:

Flow Rate (GPM)	DRY	½	½	IMPROVEMENT %	1	1	IMPROVEMENT %
Tread Design	Siped	Unsiped	Siped		Unsiped	Siped	
Decel (ft/sec^2)	13.5	3.5	9.6	174	1.9	2.58	36
Torque (in-lbs)	87,770	62,840	83,840	33	14,410	31,440	118
Distances (ft)*	2,324	8,962	3,268	64	16,509	12,158	26

Flow Rate (GPM)	2	2	IMPROVEMENT %	3	3	IMPROVEMENT %	4	7.5
Tread Design	Unsiped	Siped		Unsiped	Siped		Siped	Siped
Decel (ft/sec^2)	0.9(HYD)	1.33	48	(HYD)	1.16	-	1.16	1.28
Torque (in-lbs)	--	2,620	-	1,965	2,620	33	1,965	1,965
Distances (ft)*	--	23,585	-	--	27,041	-	27,041	--

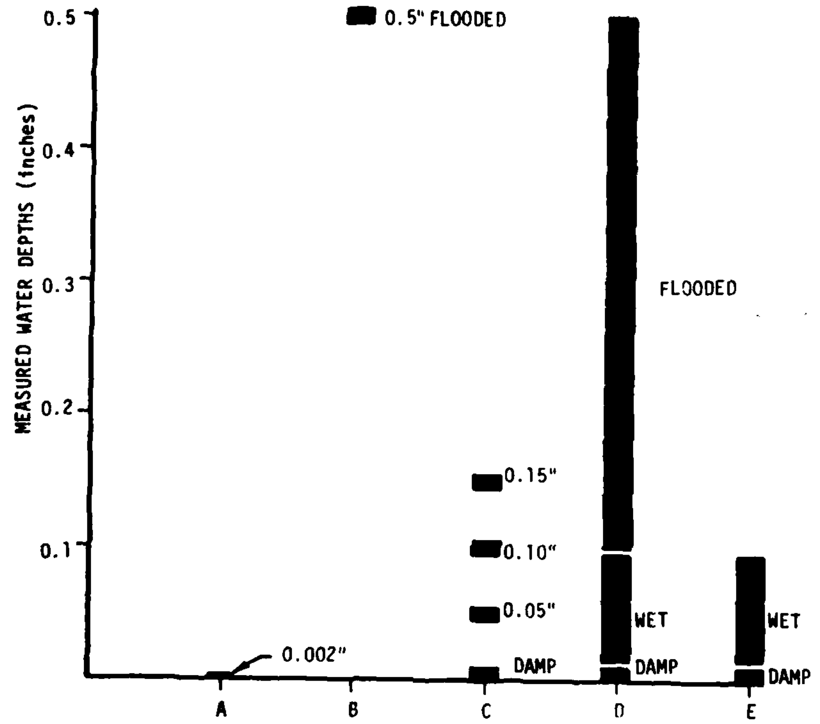
WATER APPLIED AFTER TIRE LANDS:

Flow Rate (GPM)	½	½	IMPROVEMENT %	1	1	IMPROVEMENT %	2	2	IMPROVEMENT %	3	3	IMPROVEMENT %
Tread Design	Unsiped	Siped		Unsiped	Siped		Unsiped	Siped		Unsiped	Siped	
Decel (ft/sec^2)	4.9	8.5	74	1.44	2.50	74	0.9(HYD)	1.12	24	0.9(HYD)	1.04	16
Torque (in-lbs)	76,635	91,700	20	16,375	34,715	112	--	2,620	--	--	2,620	--
Distances (ft)*	6,402	3,690	42	21,783	12,547	42	--	28,007	--	--	30,161	--

*Distances listed are calculated values based on measured deceleration rates for entire speed range of 180 mph to 57 mph in order to make valid comparisons.

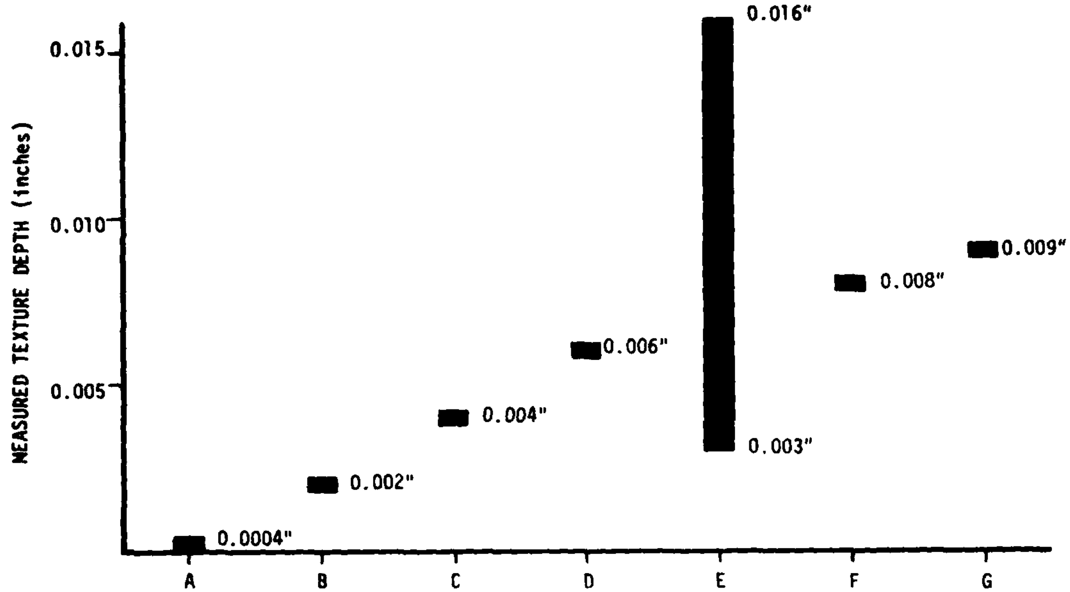
APPENDIX B

FIGURES AND PHOTOGRAPHS



A - High speed 120 (in) dynamometer tests at LGDF, WPAFB (Marcy siped tire)
B - Low speed TFM tests at LGDF, WPAFB (Marcy siped tire)
C - High speed track tests at Navy track, Lakehurst (Marcy siped tire)
D - High speed track tests at NASA track, Langley (rain tire tests)
E - High speed aircraft tests on various runways (combat traction tests)

Figure 1. Water Depth Comparison for Various Facility Traction Tests



A - TFM aluminum surface at LGDF, WPAFB (Marcy siped tire tests)*
B - 120 inch dynamometer steel surface at LGDF, WPAFB (Marcy siped tire tests)*
C - TFM tungsten surface at LGDF, WPAFB (Marcy siped tire tests)*
D - NASA Landing Loads Track cement surface at NASA LRC (rain tire tests)**
E - Range of actual runway measured texture depths (combat traction tests)**
F - Typical or average runway texture depth (combat traction tests)**
G - Navy track cement surface at Lakehurst (Marcy siped tire tests)*

*Surface texture measured per reference 3 method
**Surface texture data taken from references 1 and 2.

Figure 2. Relative Surface Textures of Test Facilities and Runways

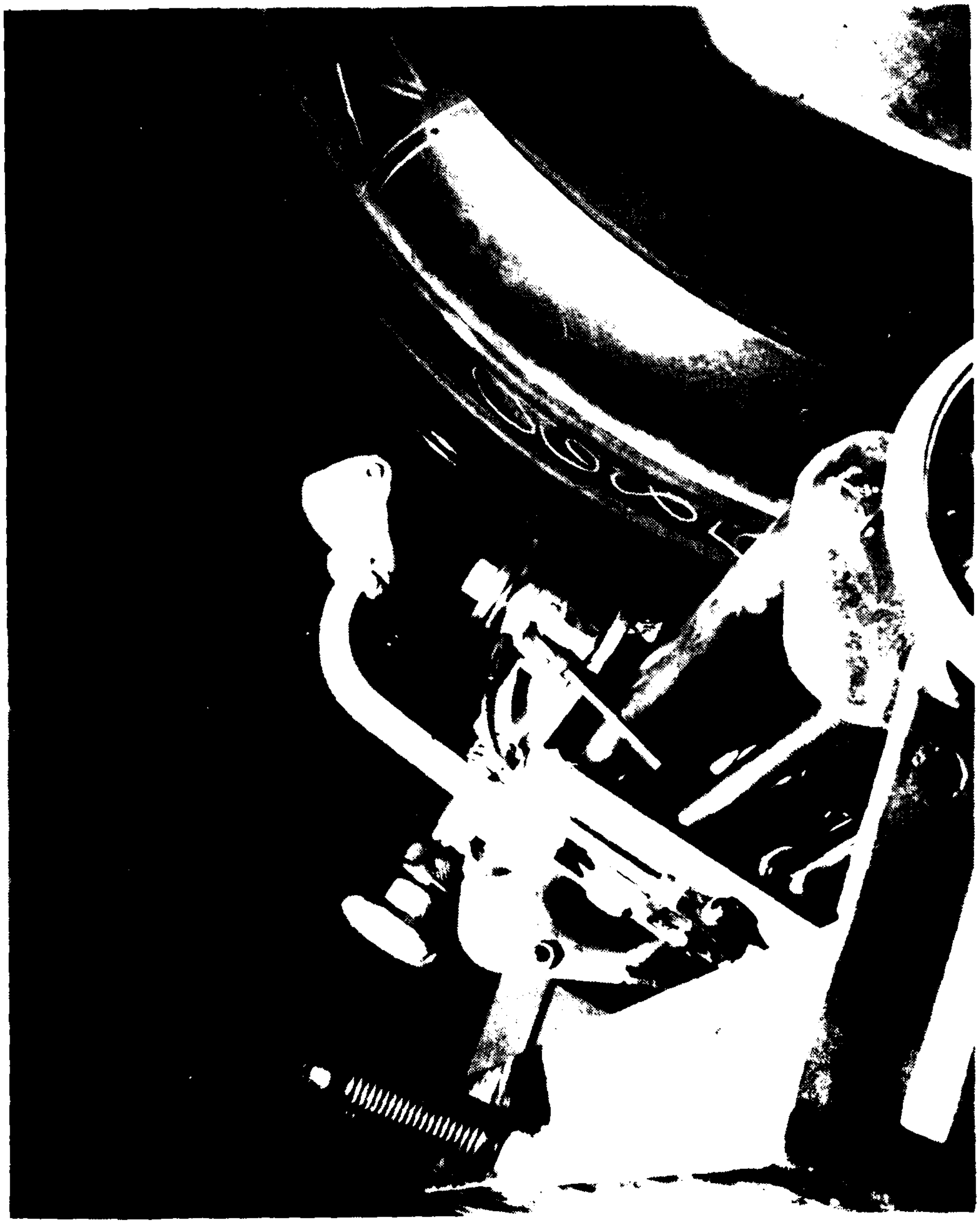


Figure 3. Marcy Siping Machine Siping F-4 Main Tire

Figure 4. Marcy Helix Sipe-Cutting Blade

Figure 5. Marcy Tread Sipe Configuration, T-3 Tire

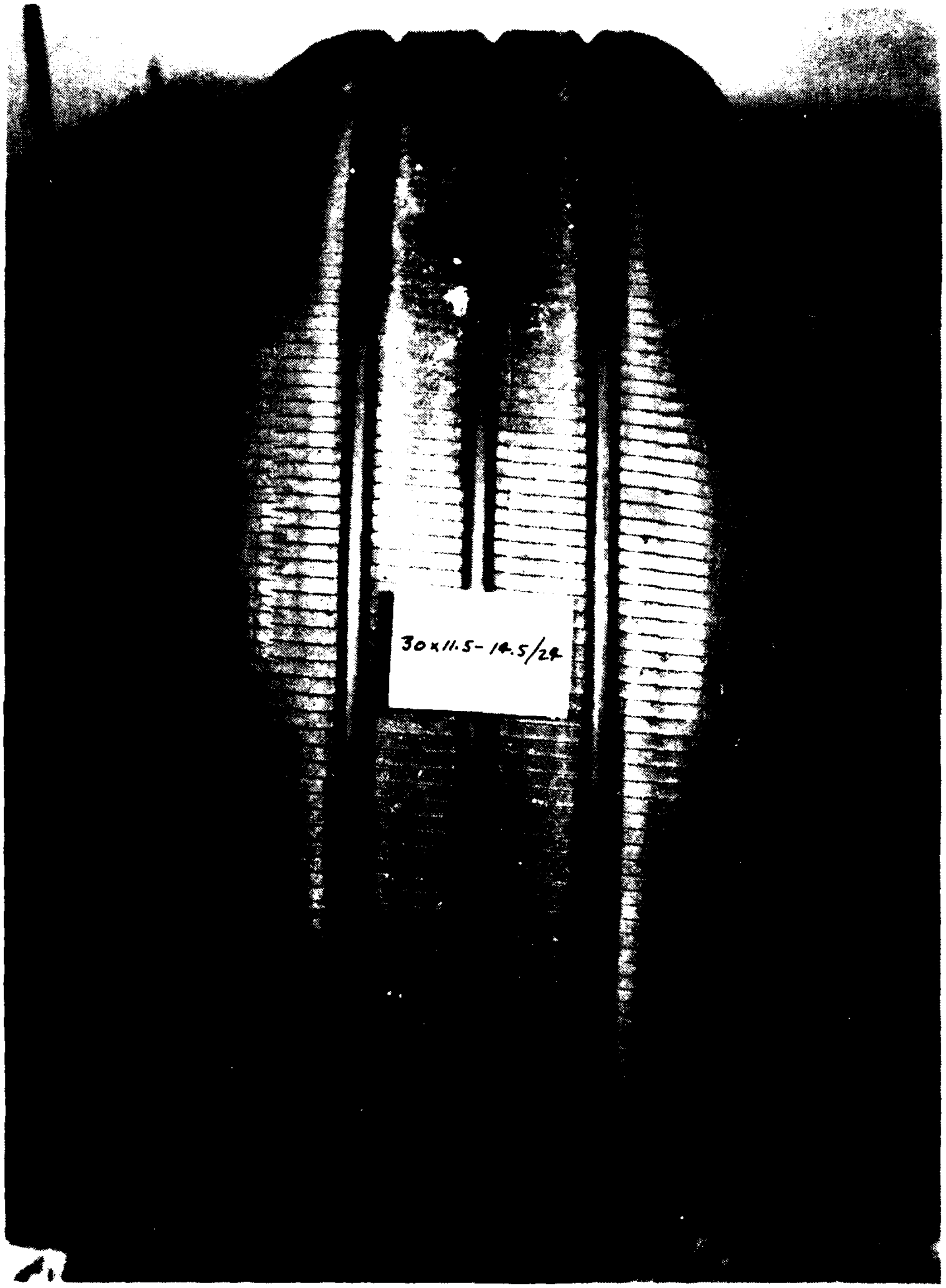


Figure [illegible] Ma[illegible] Tread Type F-3 Tire, [illegible] Inc[illegible]
[illegible]

Figure 7. Marcy Tread Sipe, F-16 Tire, 7/32 Inch Deep by 3/16 Inch Spacing

Figure 8. Marcy Tread Sipe, KC-135 Tire, 4/32 Inch Deep by 3/16 Inch Spacing

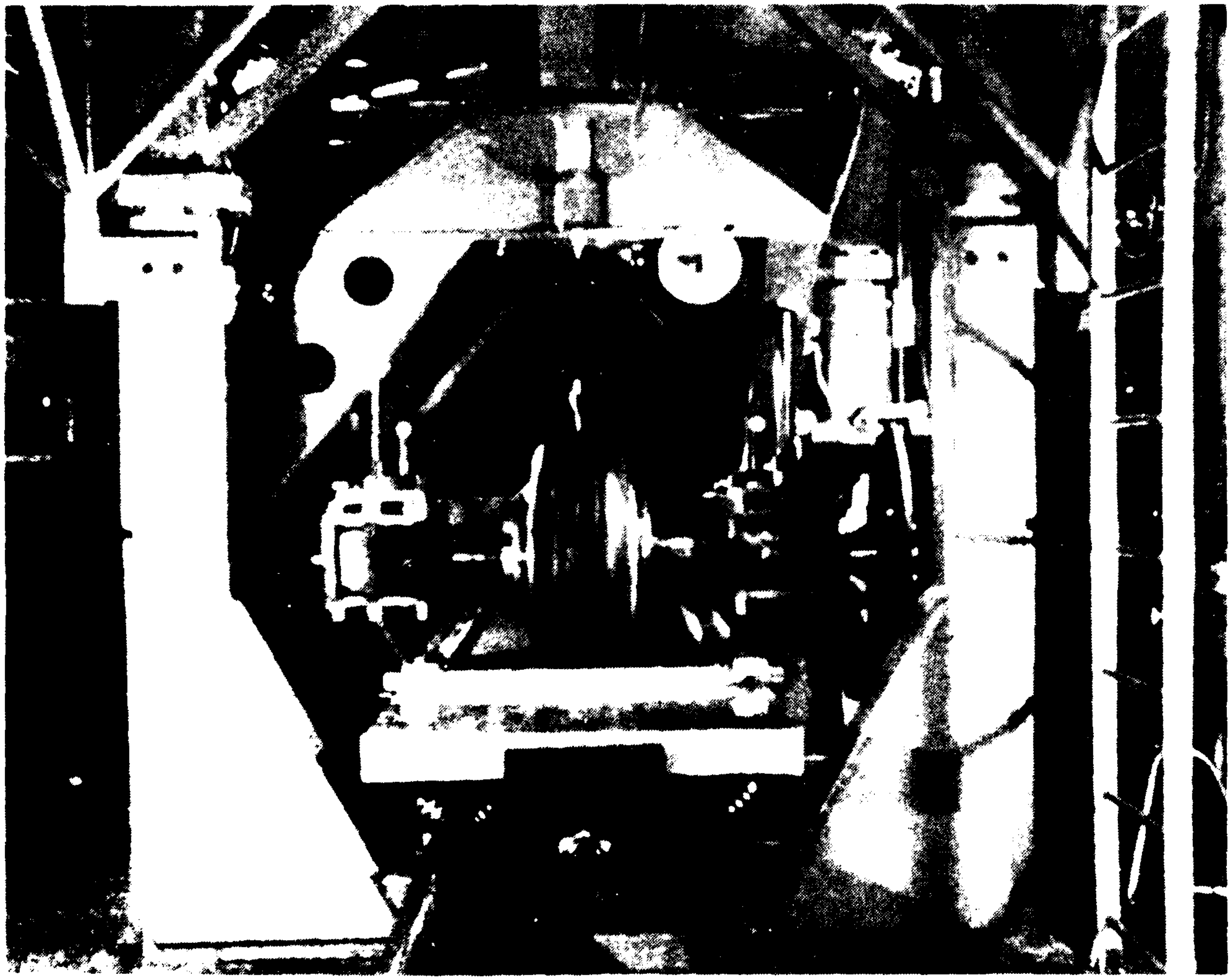


Figure 9. TEM Test Set-Up, F-4 Flooded Traction Tests

Figure 10. TTM F-4 Flooded Traction Tests

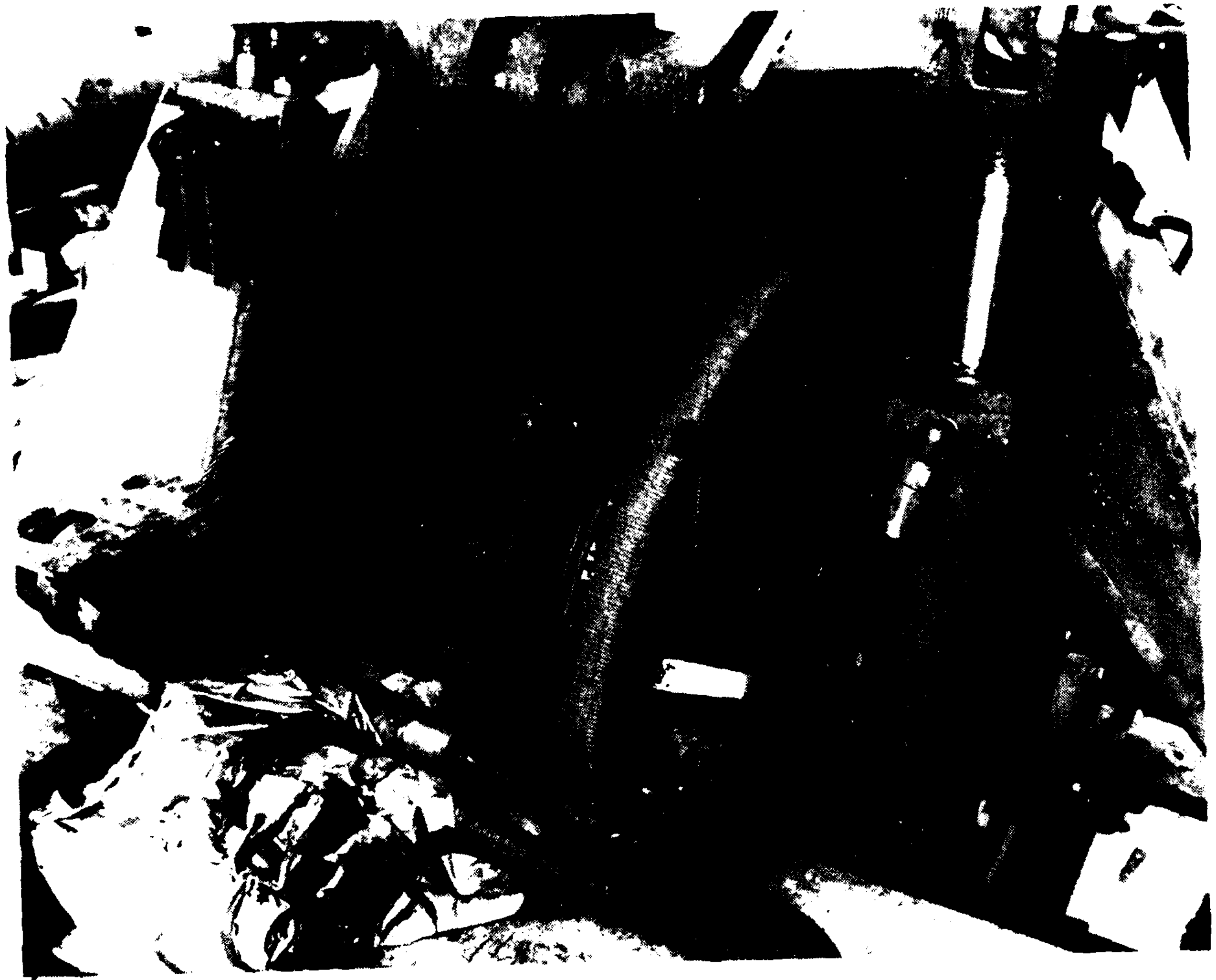


Figure 11. NAFEC/NAEC Dynamometer and KC-135 Tire/Wheel Assembly - Test Track Set-Up

Figure 12. NAFEC/NAEC Test Track #1, 200 Foot Test Section

Figure 13. NAFEC/NAEC Test Track #1, Broomed Surface Finish

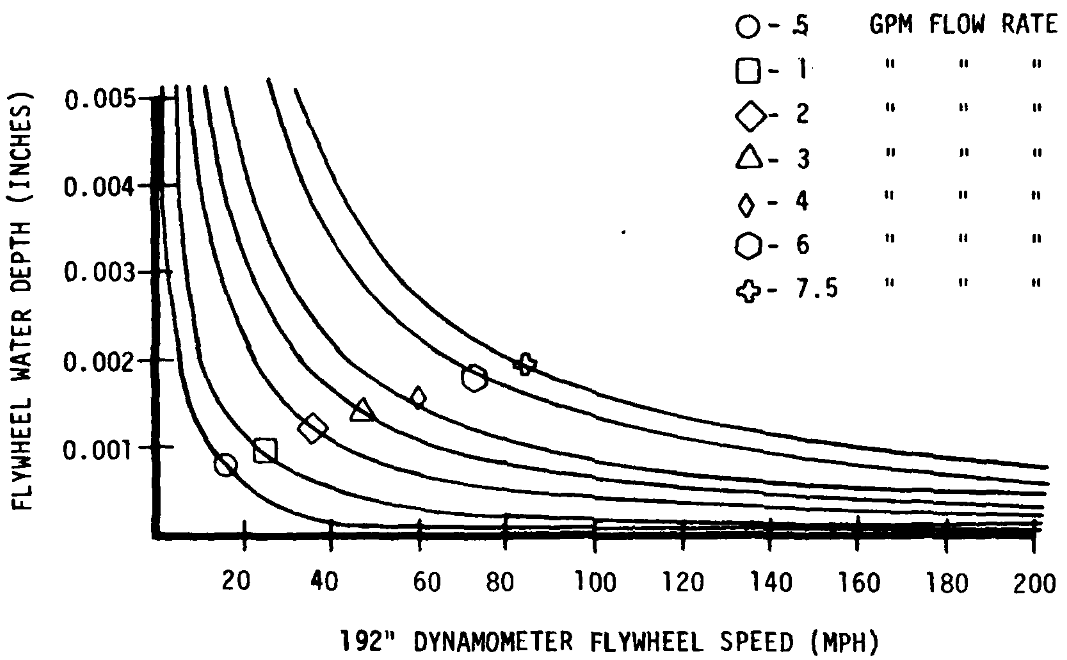


Figure 14. Approximate Flywheel Water Depth vs Flywheel Speed for Various Water Flow Rates

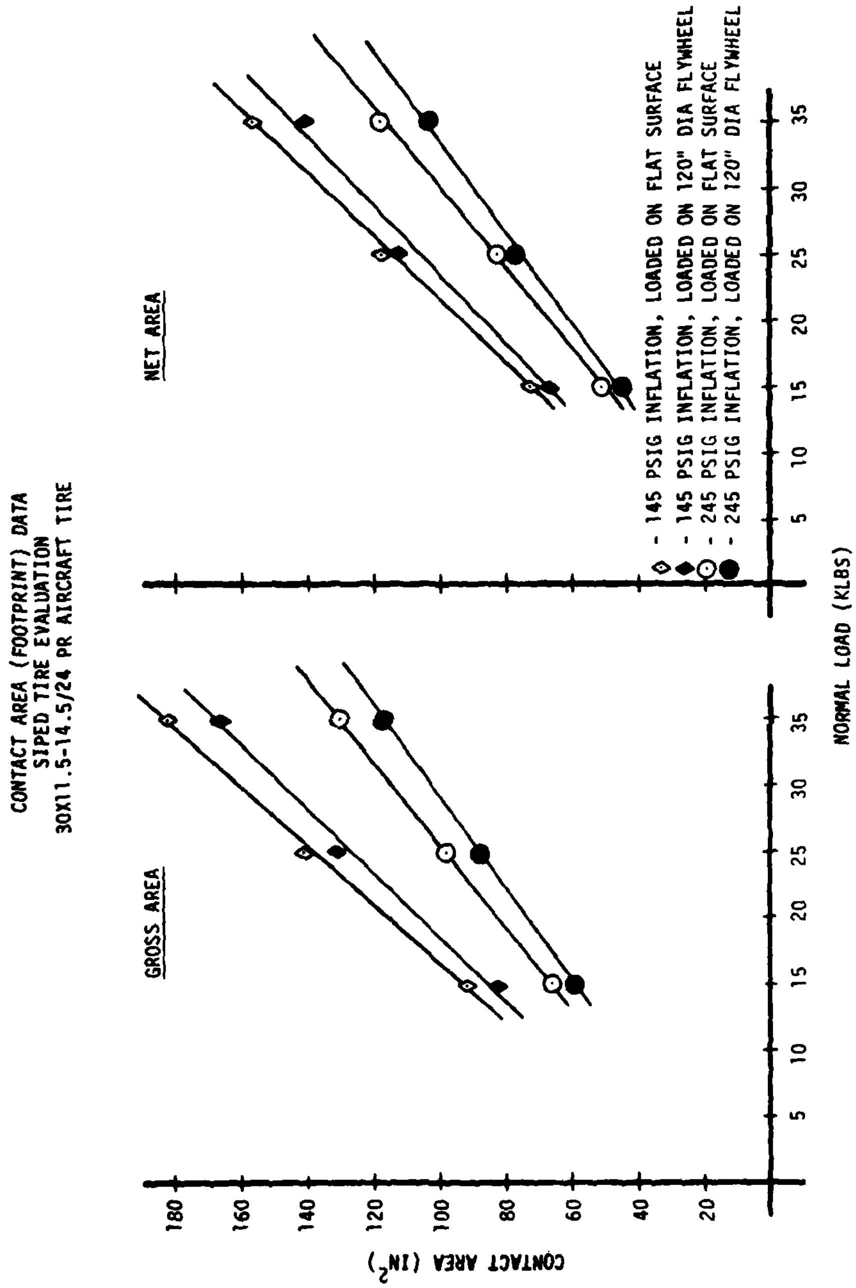


Figure 15. Contact Area vs Normal Load

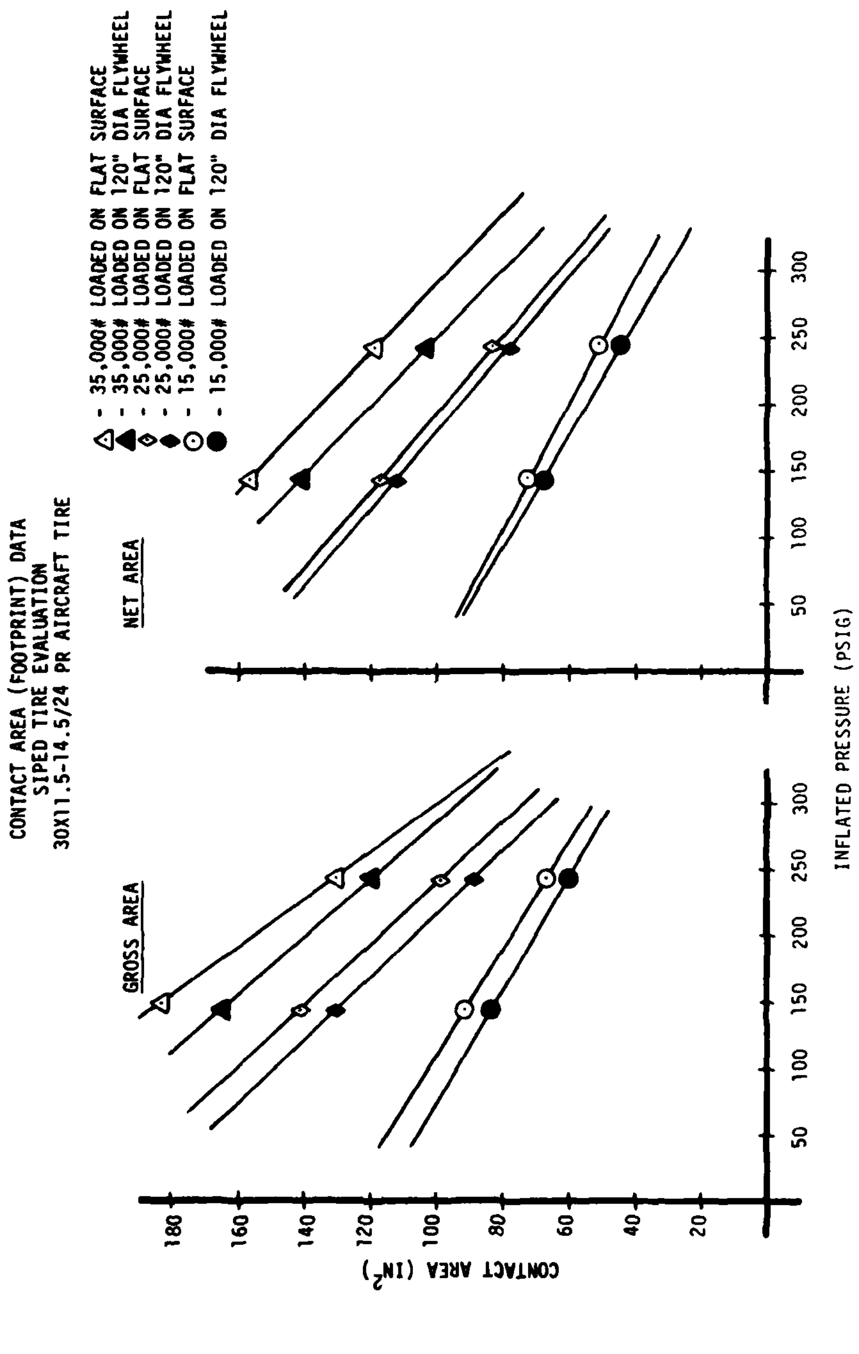


Figure 16. Contact Area vs Inflation Pressure

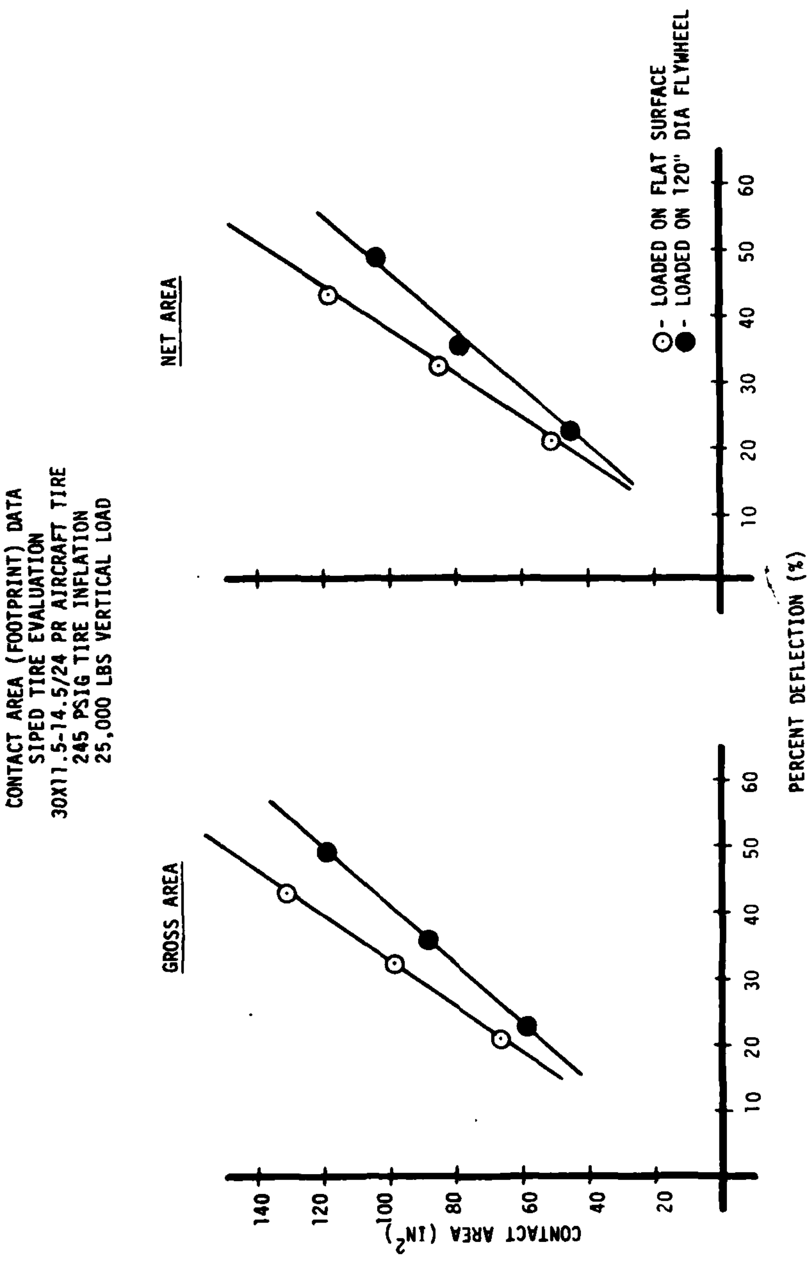


Figure 17. Contact Area vs Percent Deflection, 245 Psig Pressure

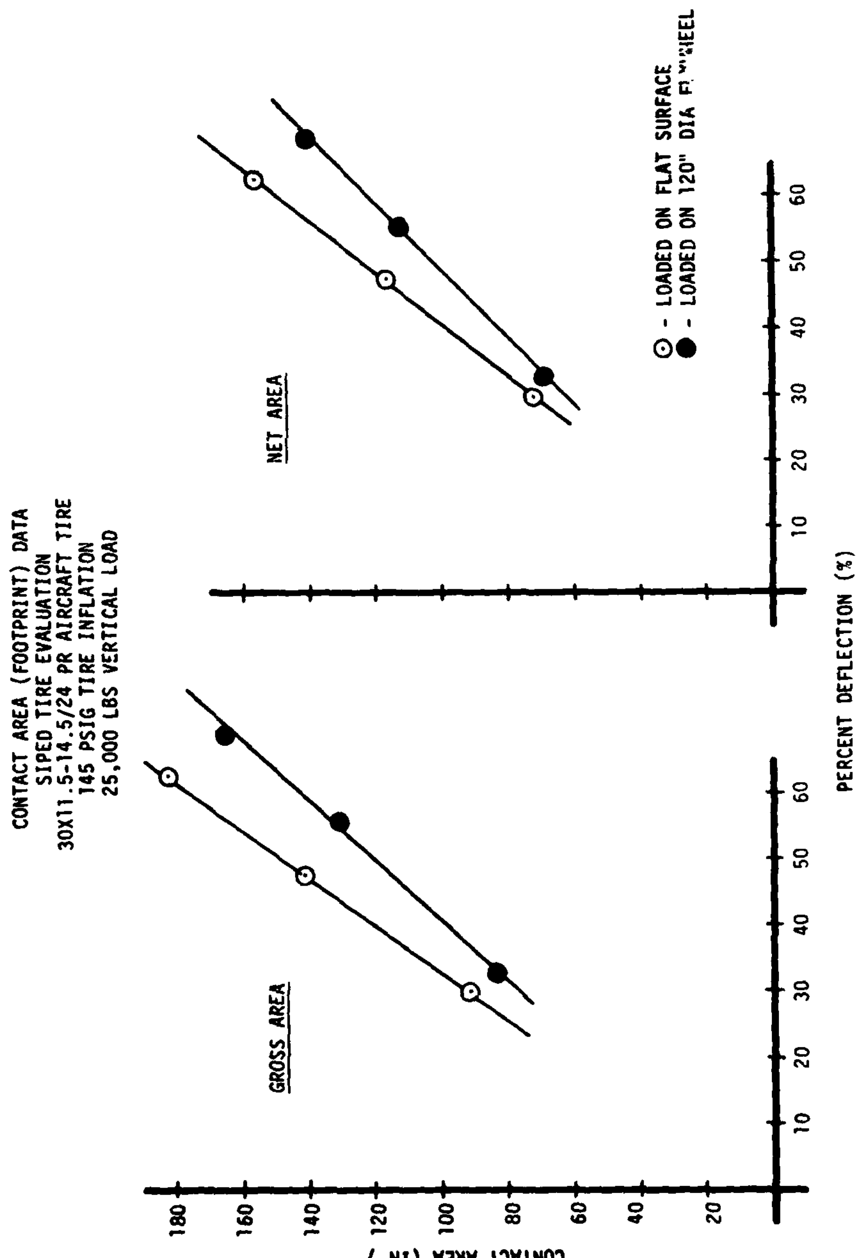


Figure 18. Contact Area vs Percent Deflection, 145 Psig Pressure

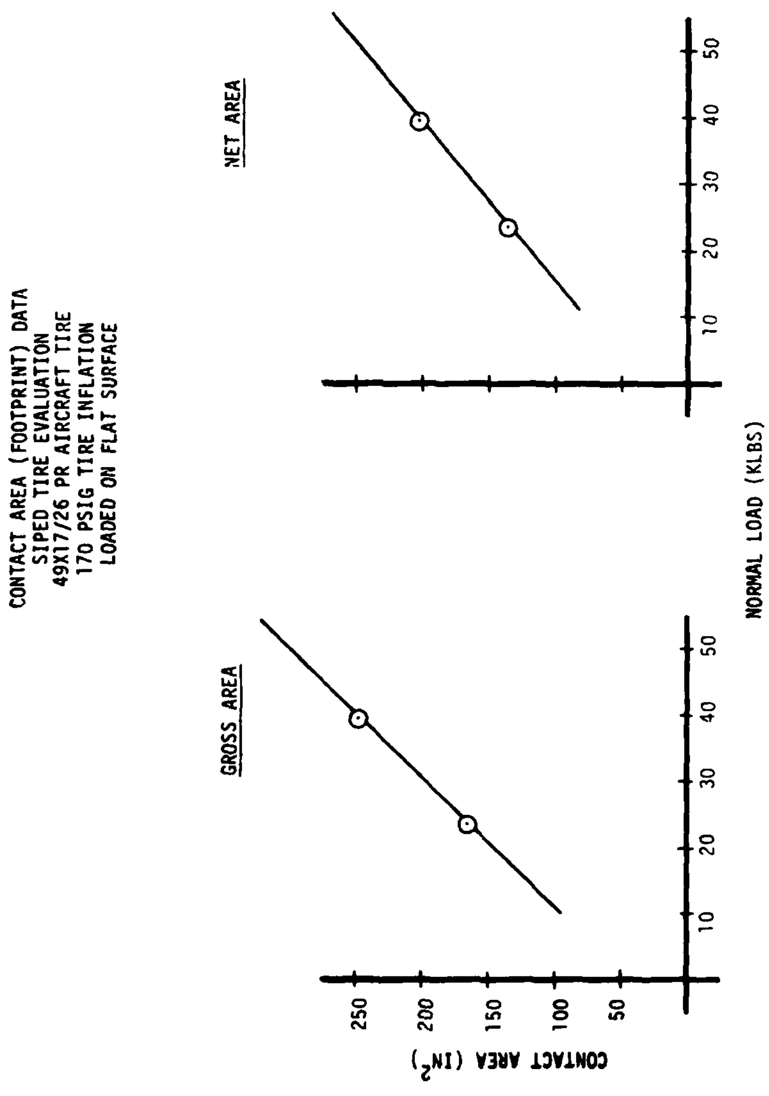


Figure 19. Contact Area vs Normal Load

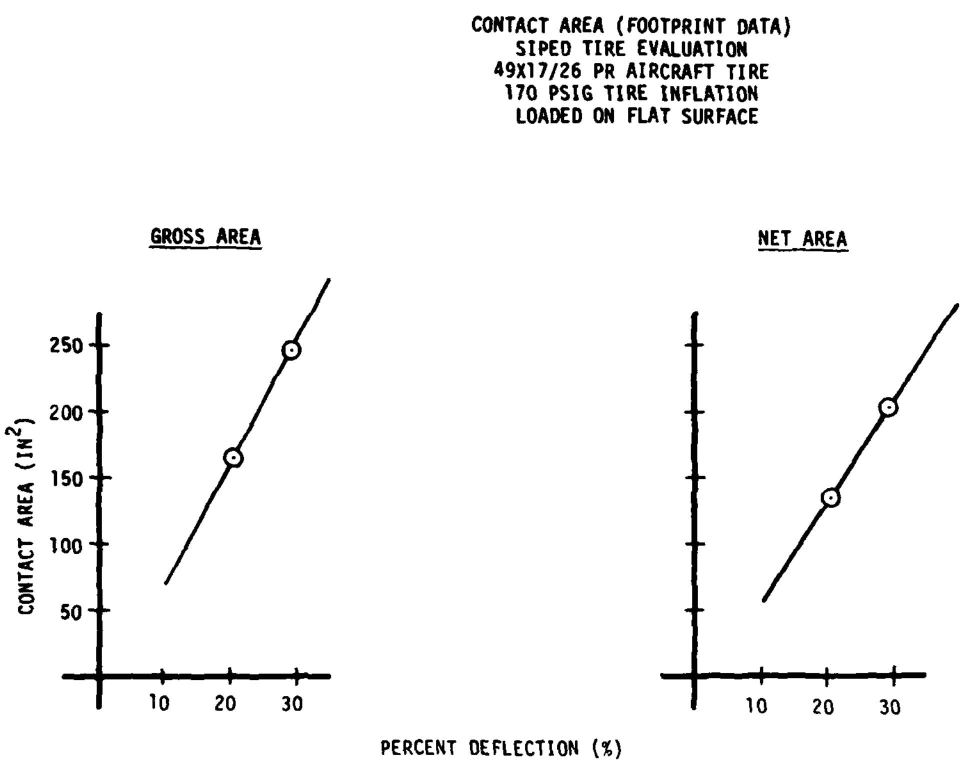


Figure 20. Contact Area vs Percent Deflection

TFM DATA
SIPED TIRE EVALUATION
30X11.5-14.5/24 PR AIRCRAFT TIRE
ALUMINUM SURFACE-AVERAGE TEXTURE DEPTH (0.0004 IN)
FLOODED (1/2 IN WATER DEPTH)
25,000 LBS VERTICAL LOAD, 243 PSIG PRESSURE

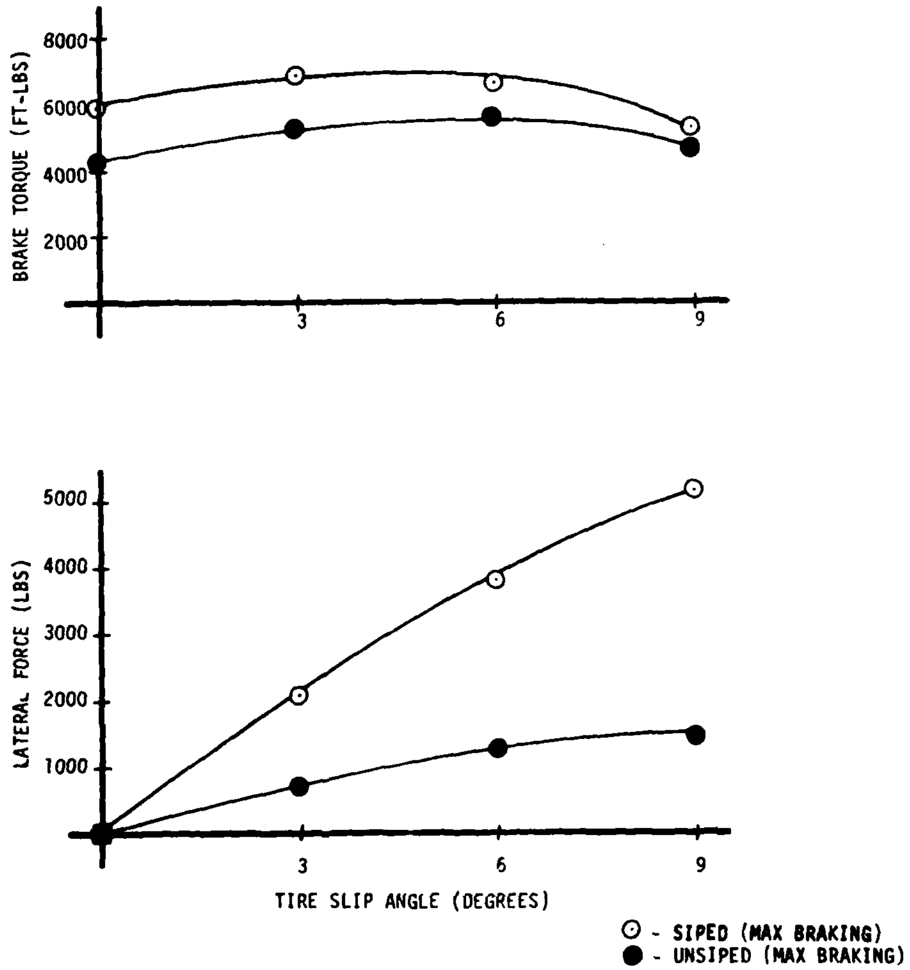


Figure 21. Brake Torque and Lateral Force vs Slip Angle, Flooded Surface, Tire Code Number 3-N (Siped 8/32" Deep X 3/16" Spacing)

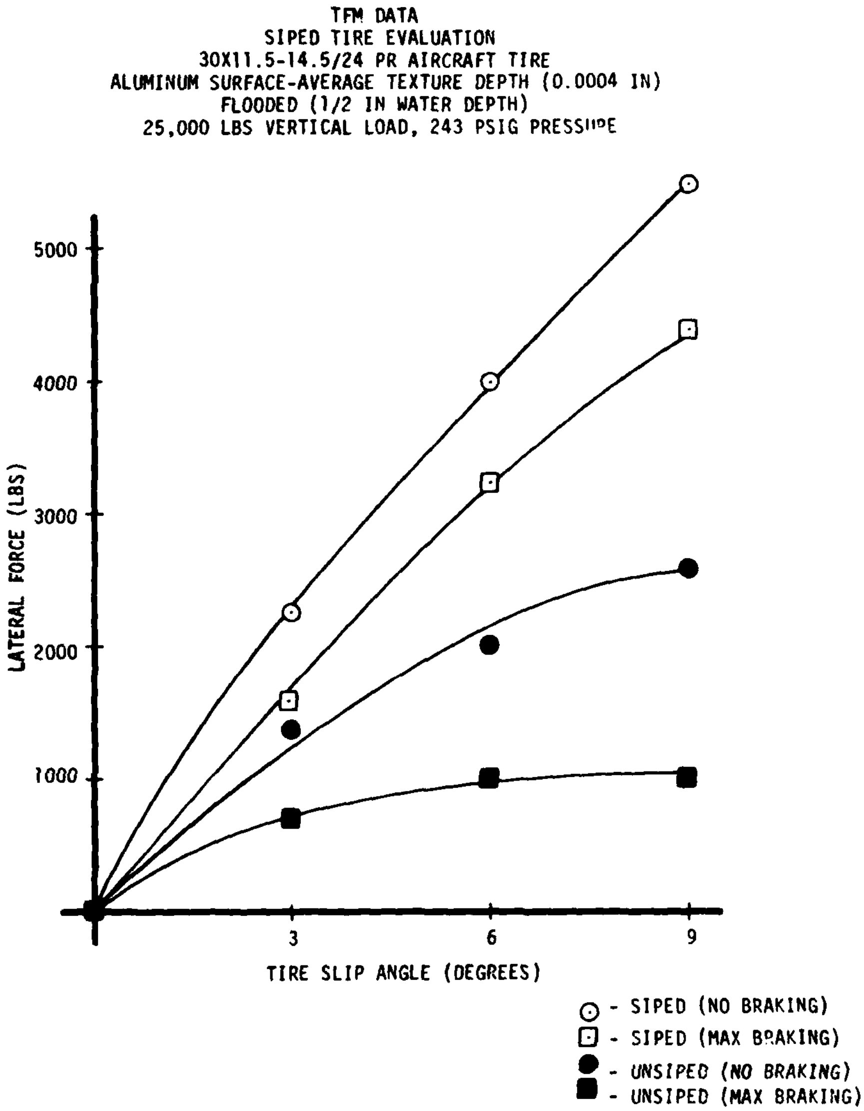


Figure 22. Lateral Force vs Slip Angle, Flooded Test Surface, Tire Code Number 5-N (Siped 9/32" Deep X 3/16" Spacing)

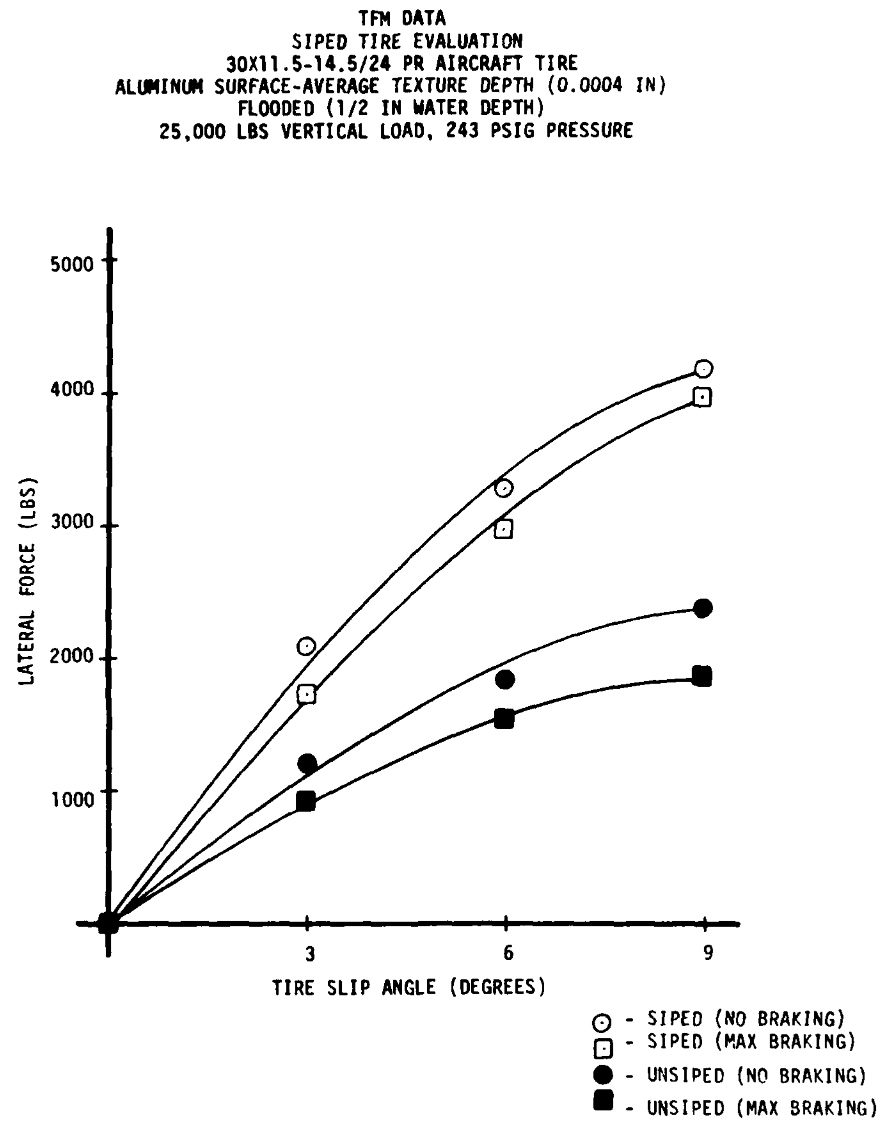


Figure 23. Lateral Force vs Slip Angle, Flooded Test Surface, Tire Code Number 6-N (Siped 9/32" Deep X 1/8" Spacing)

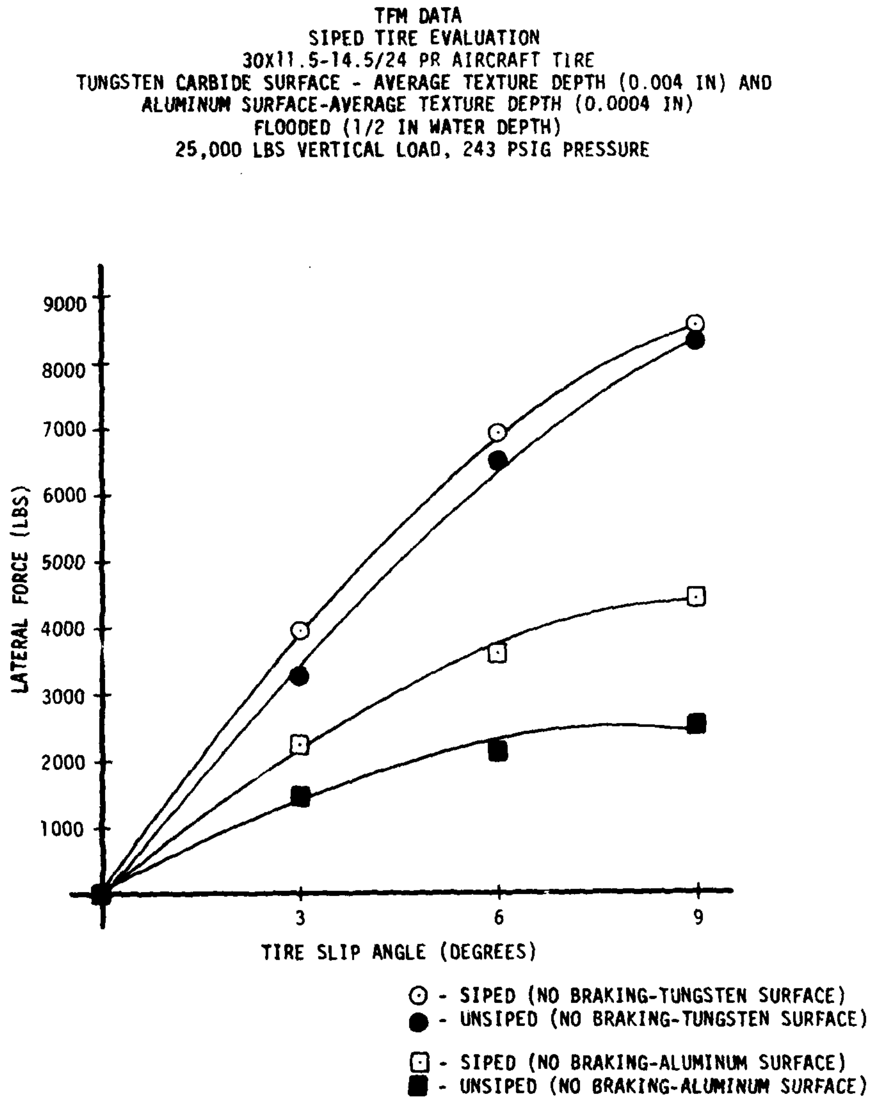


Figure 24. Lateral Force vs Slip Angle, Flooded Test Surface, Tire Code Number 11-N (Siped 5/32" Deep X 1/8" Spacing)

TFM DATA
SIPED TIRE EVALUATION
30X11.5-14.5/24 PR AIRCRAFT TIRE
TUNGSTEN CARBIDE SURFACE-AVERAGE TEXTURE DEPTH (0.004 IN) AND
ALUMINUM SURFACE-AVERAGE TEXTURE DEPTH (0.0004 IN)
(DRY SURFACE)
25,000 LBS VERTICAL LOAD, 243 PSIG PRESSURE

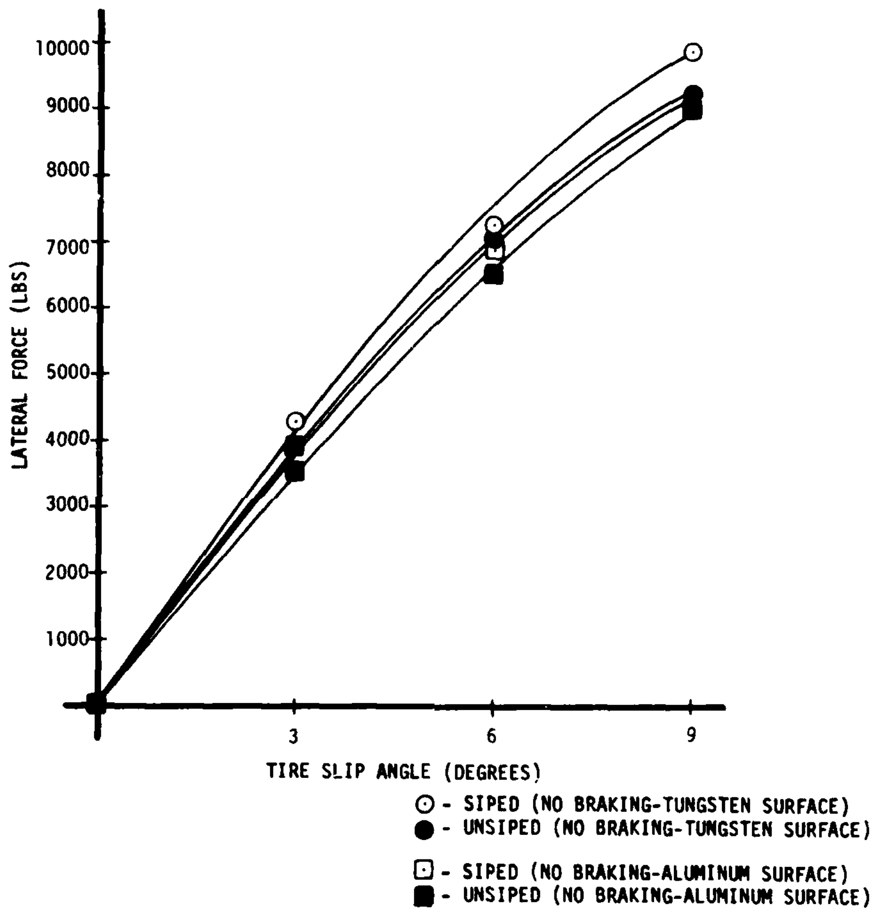


Figure 25. Lateral Force vs Slip Angle, Dry Test Surface, Tire Code Number 11-N (Siped 5/32" Deep X 1/8" Spacing)

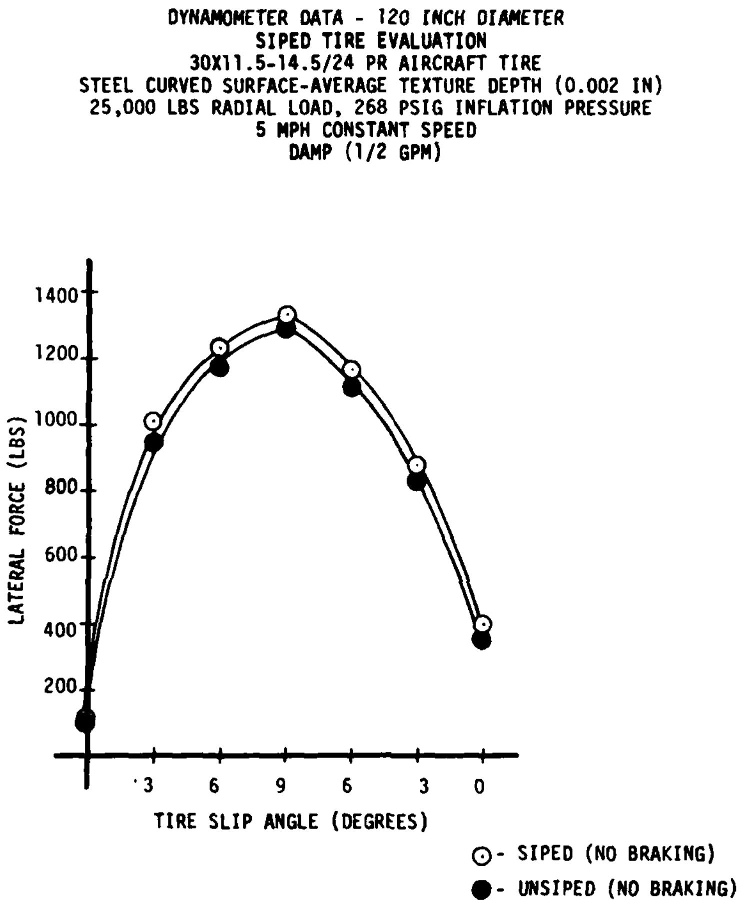


Figure 26. Lateral Force vs Slip Angle, Damp Test Surface, 5 MPH, 1/2 GPM, Tire Code Number 24-N (Siped 8/32" Deep X 3/16" Spacing)

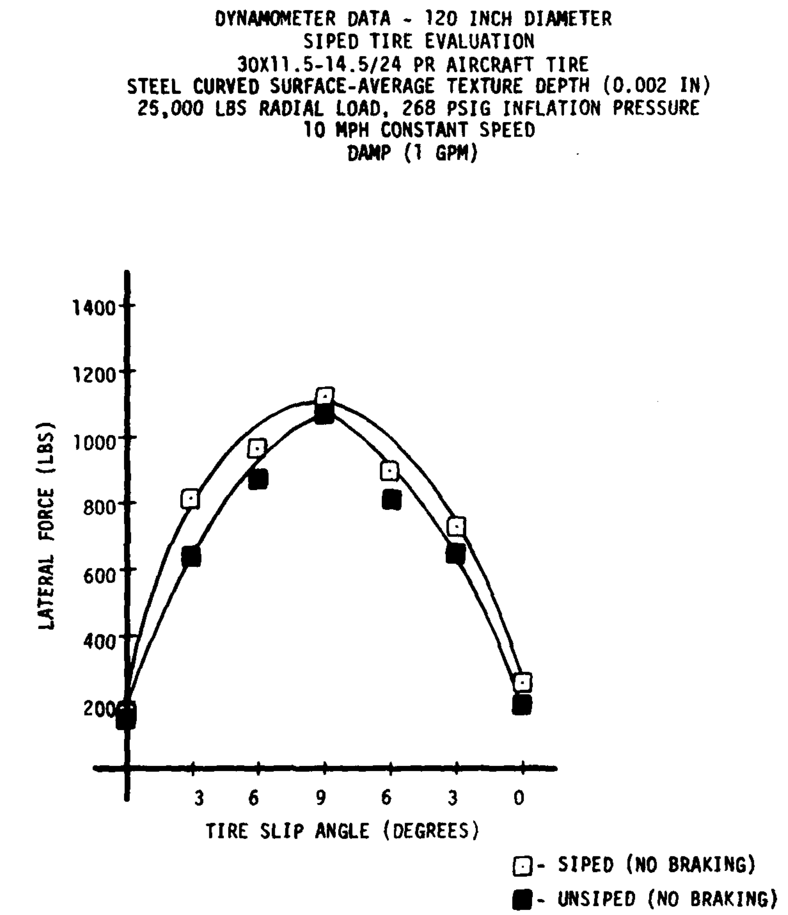


Figure 27. Lateral Force vs Slip Angle, Damp Test Surface, 10 MPH, 1 GPM, Tire Code Number 24-N (Siped 8/32" Deep X 3/16" Spacing)

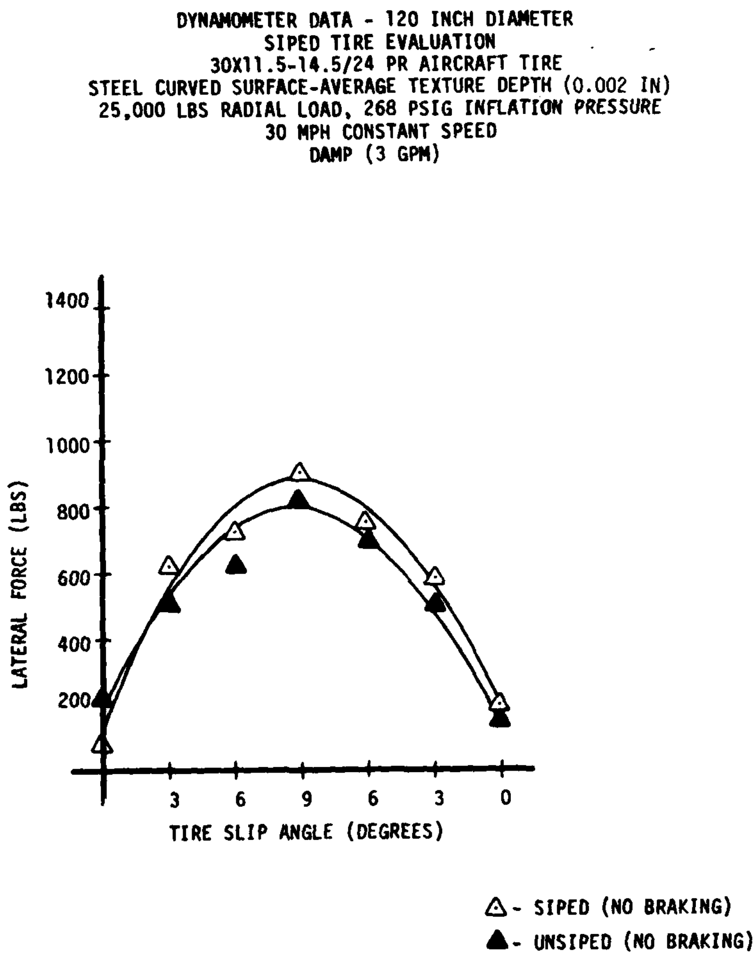


Figure 28. Lateral Force vs Slip Angle, Damp Test Surface, 30 MPH, 3 GPM, Tire Code Number 24-N (Siped 8/32" Deep X 3/16" Spacing)

DYNAMOMETER DATA - 120 INCH DIAMETER
SIPED TIRE EVALUATION
30X11.5-14.5/24 PR AIRCRAFT TIRE
STEEL CURVED SURFACE-AVERAGE TEXTURE DEPTH (0.002 IN)
25,000 LBS RADIAL LOAD, 268 PSIG INFLATION PRESSURE
60 MPH CONSTANT SPEED
DAMP (6 GPM)

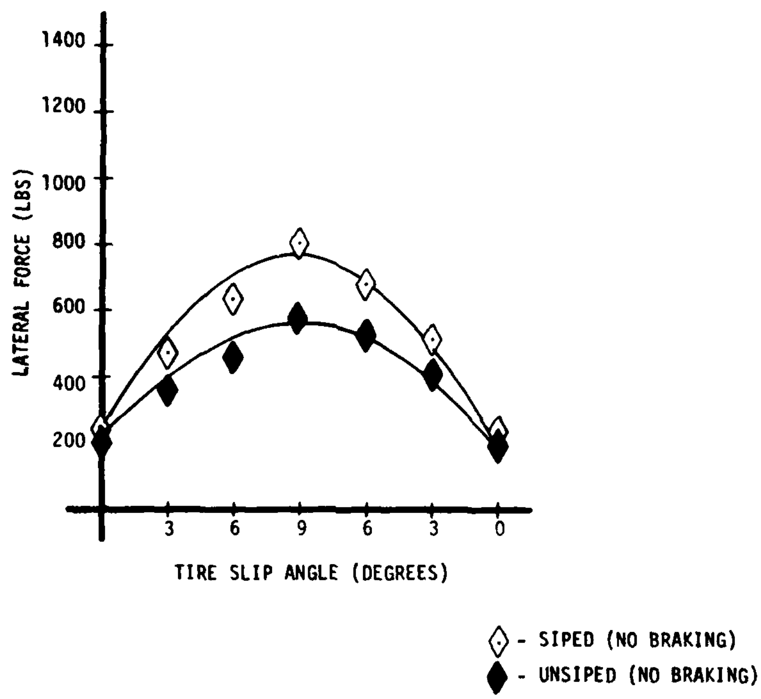


Figure 29. Lateral Force vs Slip Angle, Damp Test Surface, 60 MPH, 6 GPM, Tire Code Number 24-N (Siped 8/32" Deep X 3/16" Spacing)

DYNAMOMETER DATA - 120 INCH DIAMETER
SIPED TIRE EVALUATION
30X11.5-14.5/24 PR AIRCRAFT TIRE
STEEL CURVED SURFACE-AVERAGE TEXTURE DEPTH (0.002 IN)
25,000 LBS RADIAL LOAD, 268 PSIG INFLATION PRESSURE
60 MPH CONSTANT SPEED
DAMP (2 GPM)

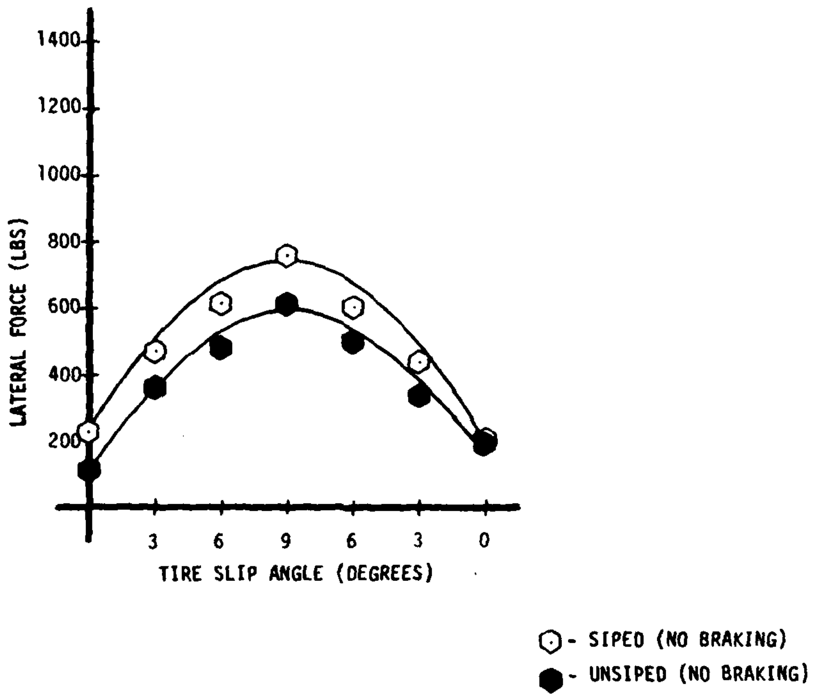


Figure 30. Lateral Force vs Slip Angle, Damp Test Surface, 60 MPH, 2 GPM, Tire Code Number 24-N (Siped 8/32" Deep X 3/16" Spacing)

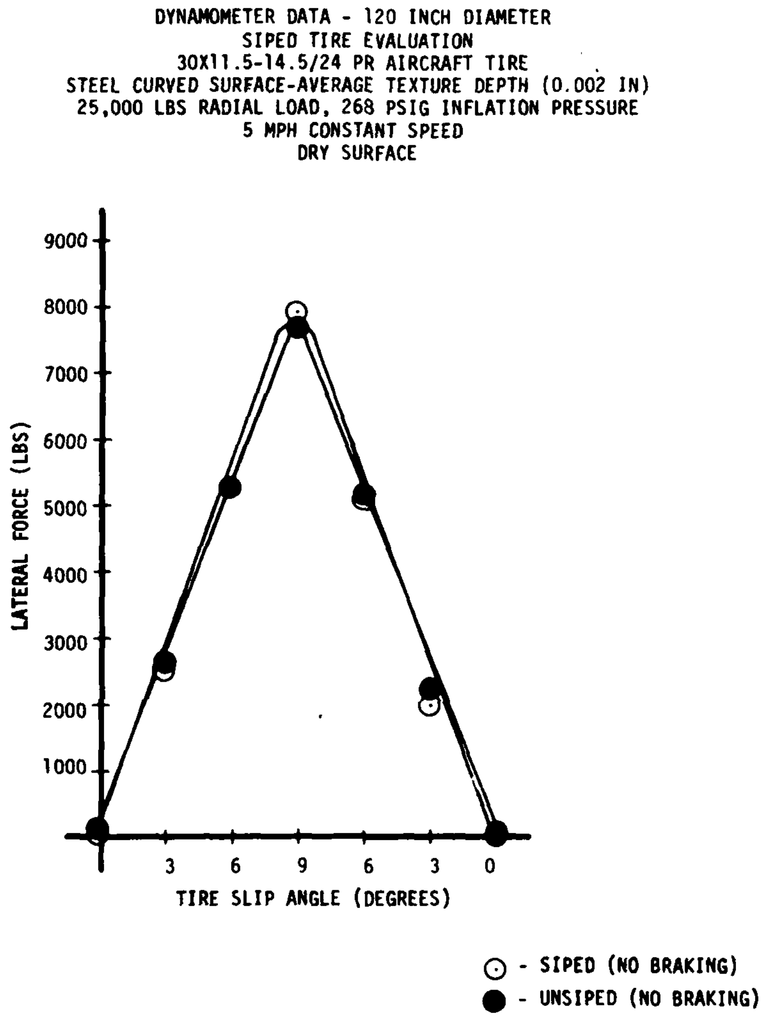


Figure 31. Lateral Force vs Slip Angle, Dry Test Surface, 5 MPH, Tire Code Number 24-N (Siped 8/32" Deep X 3/16" Spacing)

DYNAMOMETER DATA - 120 INCH DIAMETER
SIPED TIRE EVALUATION
30X11.5-14.5/24 PR AIRCRAFT TIRE
STEEL CURVED SURFACE-AVERAGE TEXTURE DEPTH (0.002 IN)
25,000 LBS RADIAL LOAD, 268 PSIG INFLATION PRESSURE
10 MPH CONSTANT SPEED
DRY SURFACE

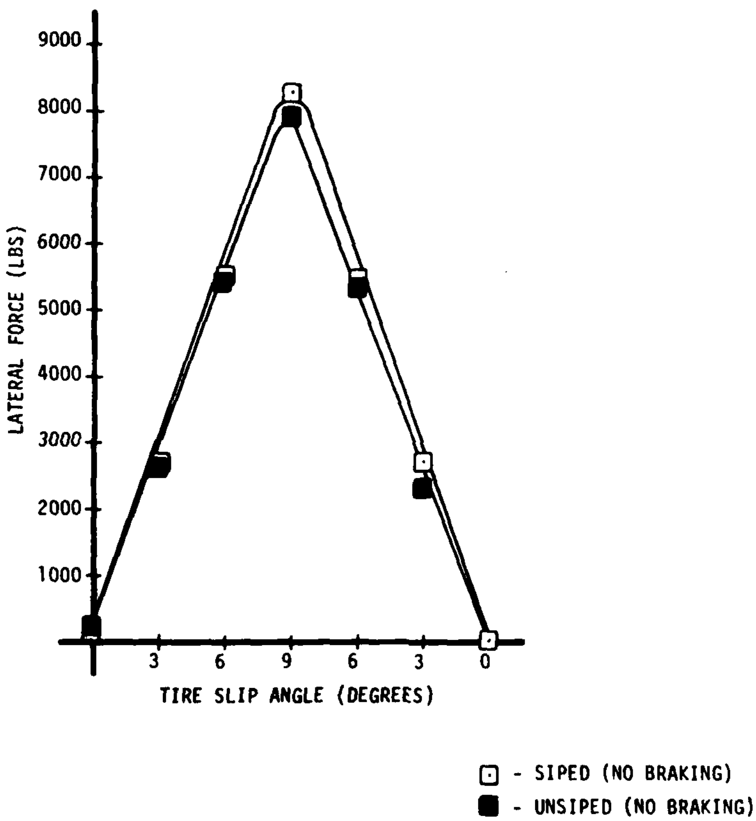


Figure 32. Lateral Force vs Slip Angle, Dry Test Surface, 10 MPH, Tire Code Number 24-N (Siped 8/32" Deep X 3/16" Spacing)

DYNAMOMETER DATA - 120 INCH DIAMETER
SIPED TIRE EVALUATION
30X11.5-14.5/24 PR AIRCRAFT TIRE
STEEL CURVED SURFACE-AVERAGE TEXTURE DEPTH (0.002 IN)
25,000 LBS RADIAL LOAD, 268 PSIG INFLATION PRESSURE
30 MPH CONSTANT SPEED
DRY SURFACE

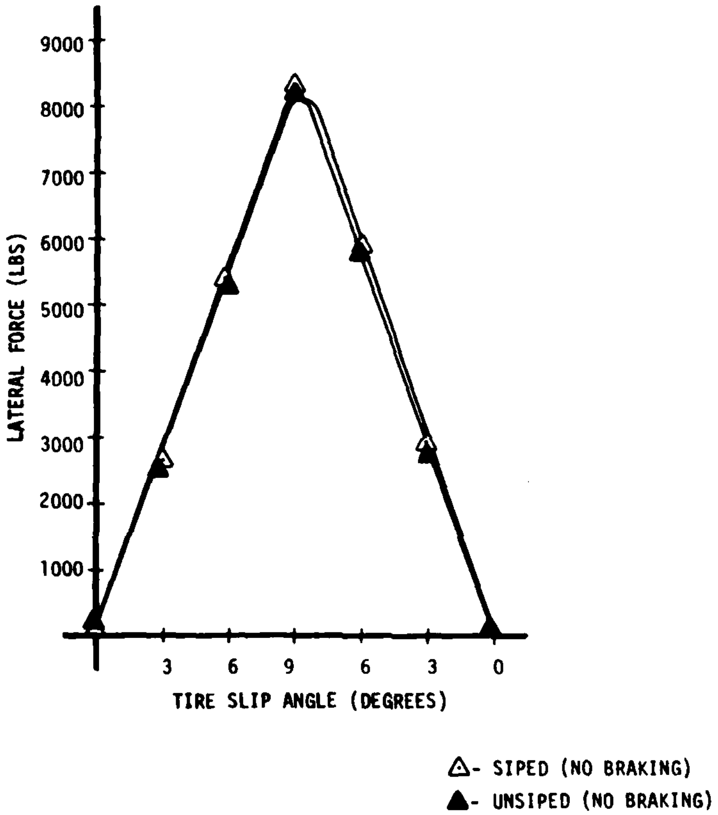


Figure 33. Lateral Force vs Slip Angle, Dry Test Surface, 30 MPH, Tire Code Number 24-N (Siped 8/32" Deep X 3/16" Spacing)

DYNAMOMETER DATA - 120 INCH DIAMETER
SIPED TIRE EVALUATION
30X11.5-14.5/24 PR AIRCRAFT TIRE
STEEL CURVED SURFACE-AVERAGE TEXTURE DEPTH (0.002 IN)
25,000 LBS RADIAL LOAD, 268 PSIG INFLATION PRESSURE
60 MPH CONSTANT SPEED
DRY SURFACE

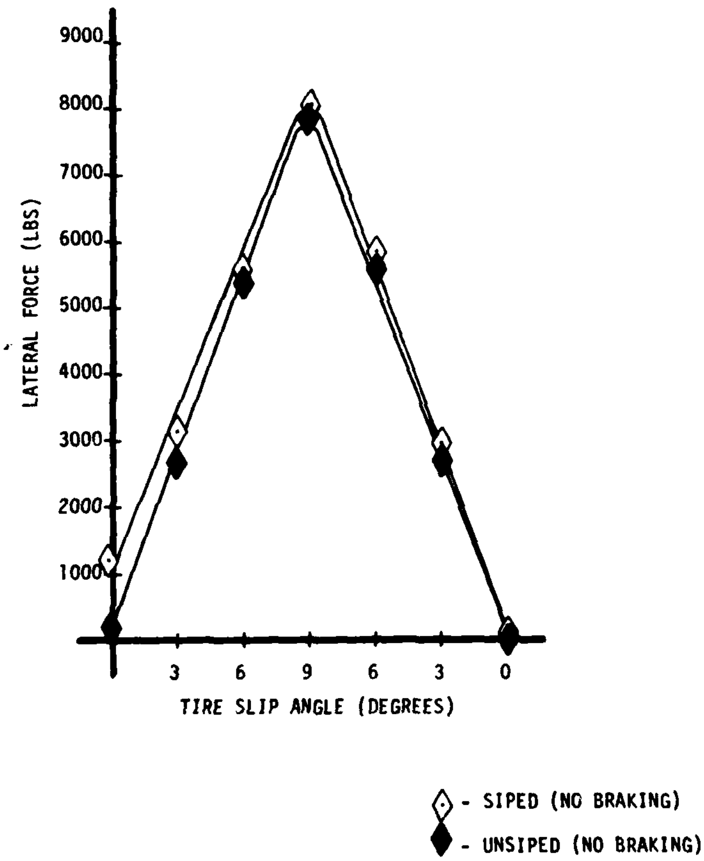


Figure 34. Lateral Force vs Slip Angle, Dry Test Surface, 60MPH, Tire Code Number 24-N (Siped 8/32" Deep X 3/16" Spacing)

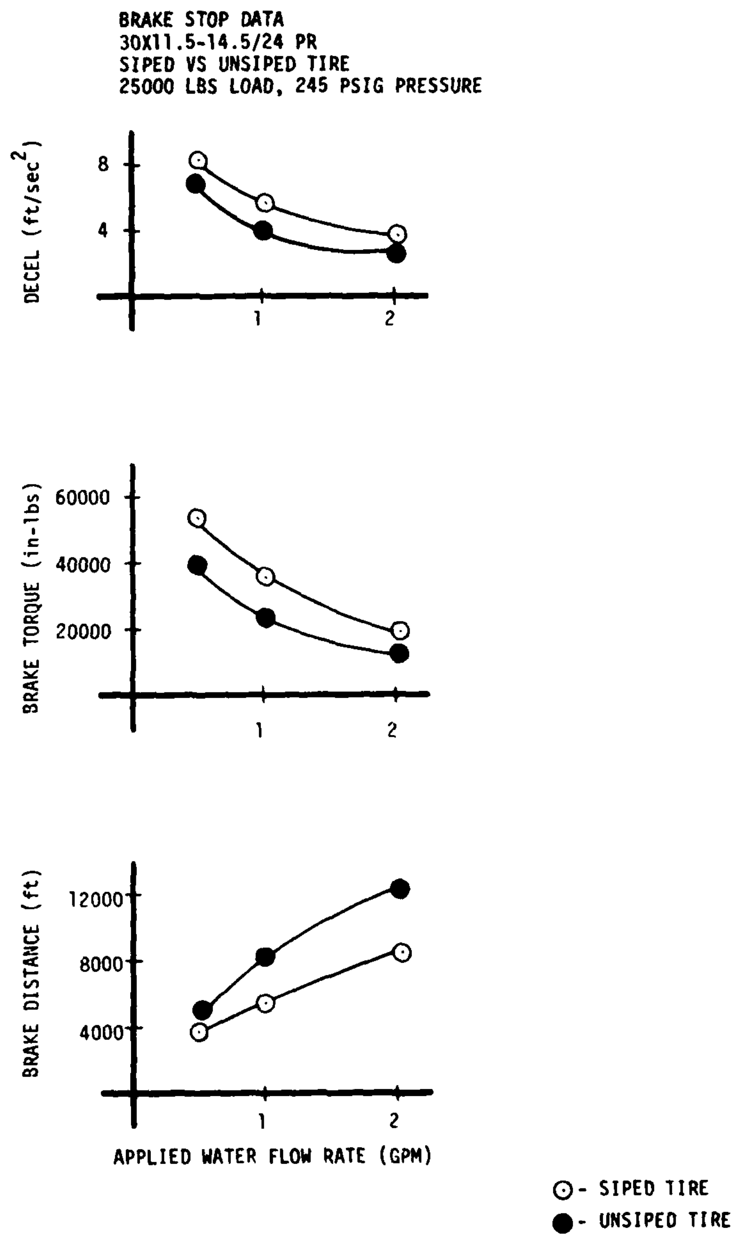


Figure 35. Brake Stop Data vs Water Flow Rate, Tire Code Number 18-N

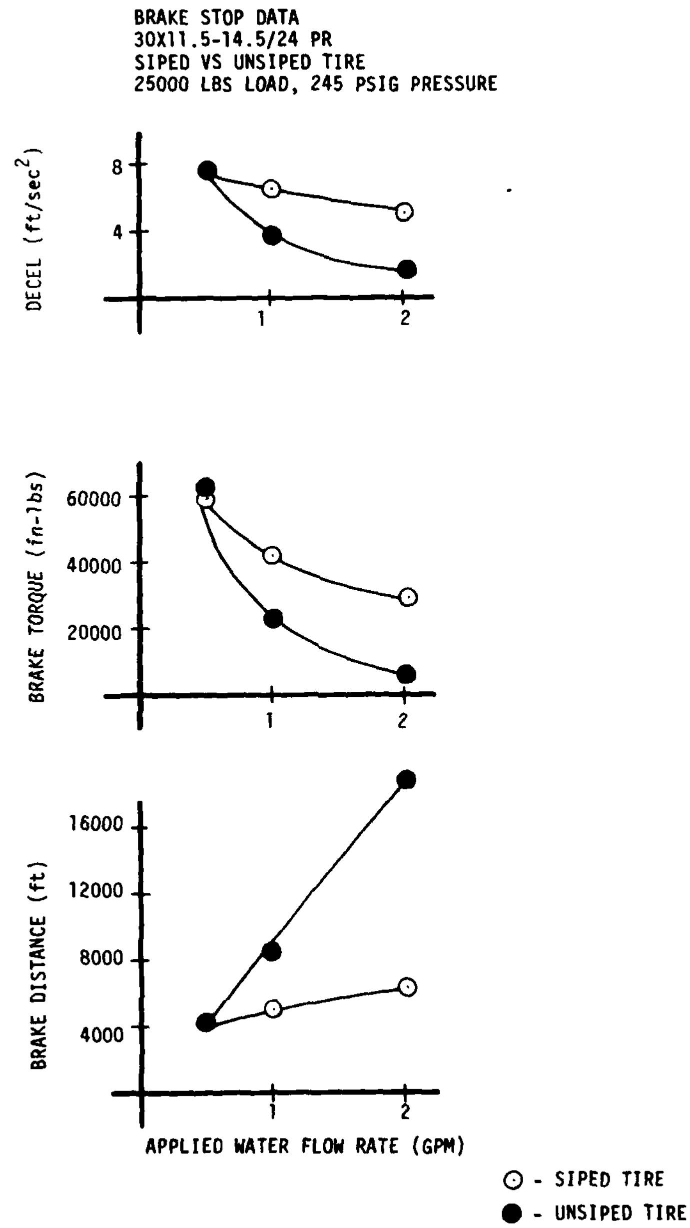


Figure 36. Brake Stop Data vs Water Flow Rate, Tire Code Number 20-N

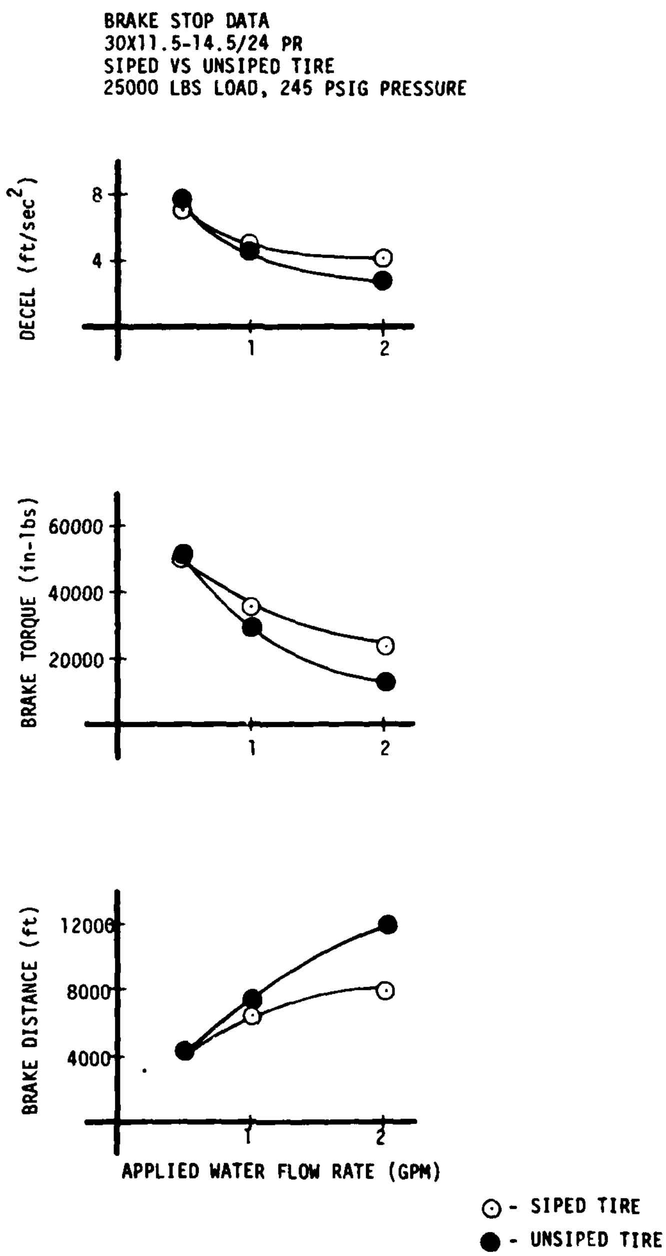


Figure 37. Brake Stop Data vs Water Flow Rate, Tire Code Number 22-N

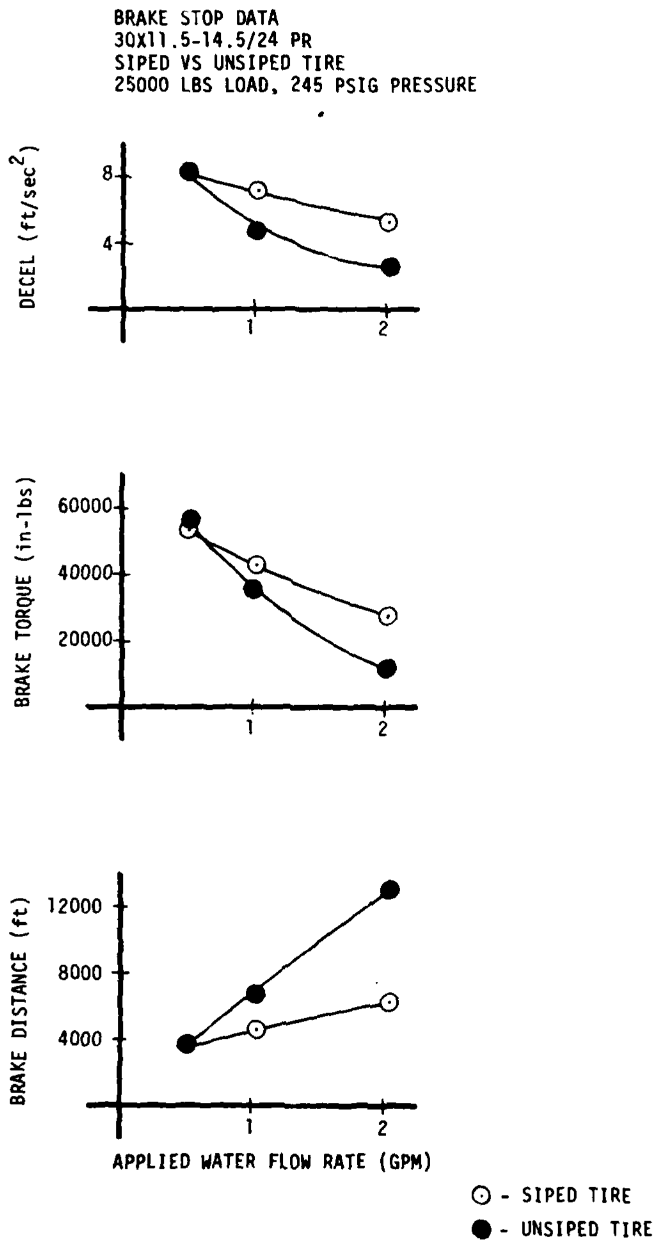
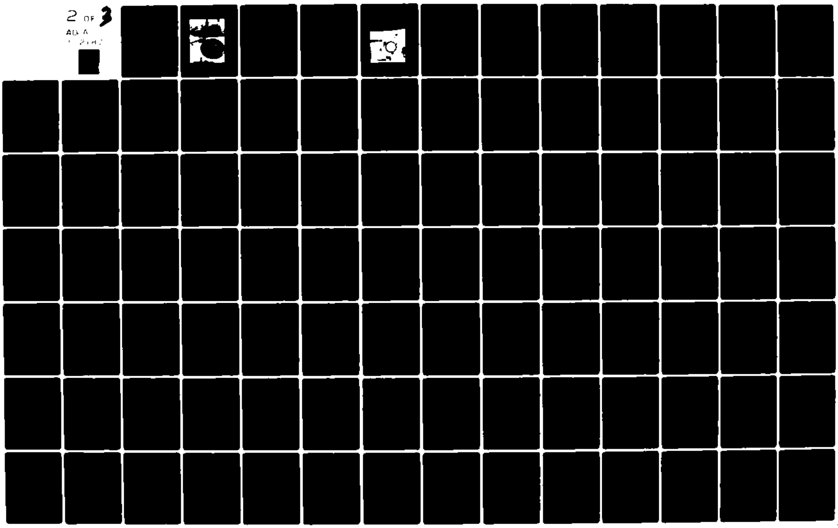


Figure 38. Brake Stop Data vs Water Flow Rate, Tire Code Number 21-N

AD-A112 187 AIR FORCE WRIGHT AERONAUTICAL LABS WRIGHT-PATTERSON AFB OH F/G 1/3
WET TRACTION TESTS - MARCY SIPED TIRE.(U)
FEB 82 P C ULRICH
UNCLASSIFIED AFWAL-TR-81-3068 NL

2 OF 3



2 OF 3

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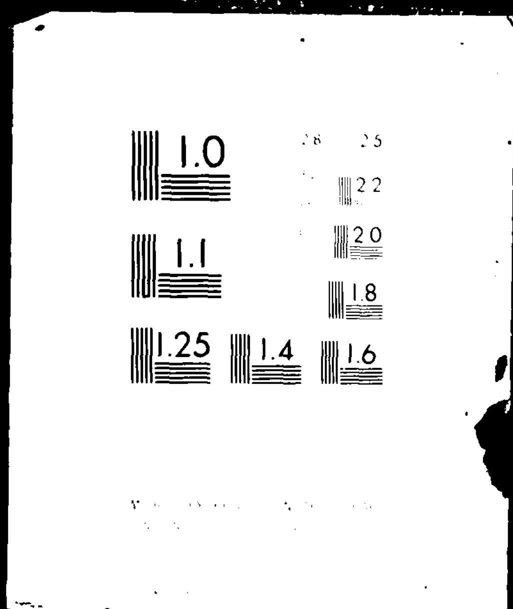
112187



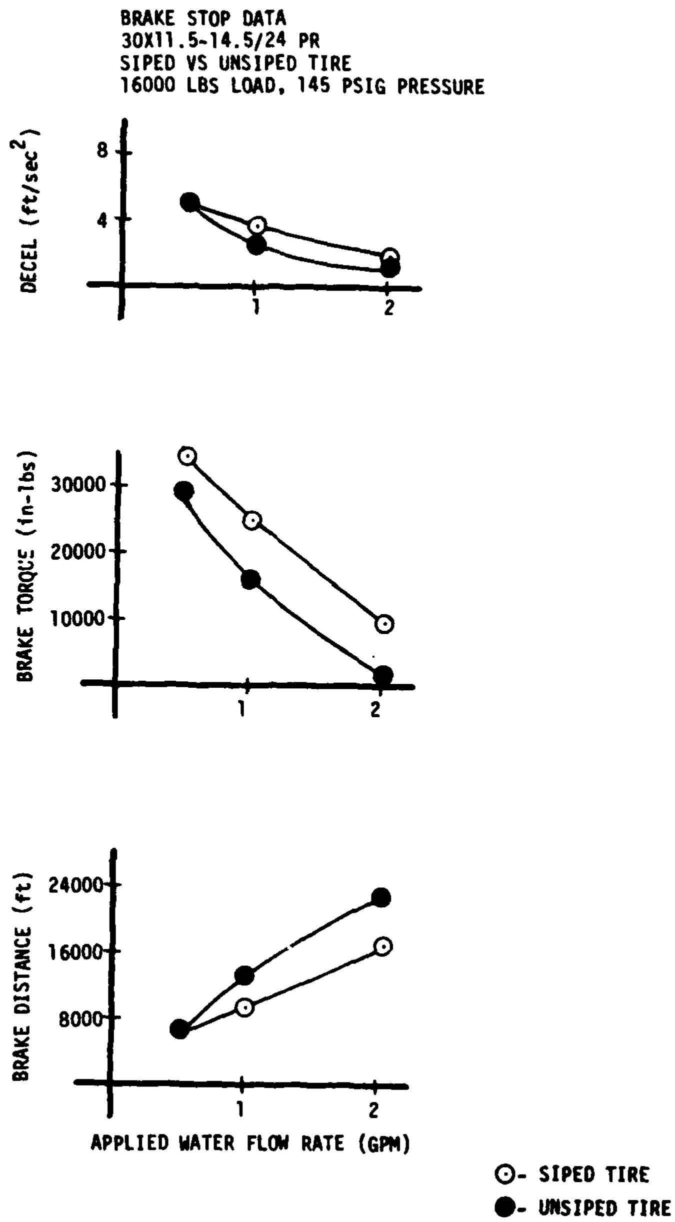


Figure 39. Brake Stop Data vs Water Flow Rate, Tire Code Number 18-N

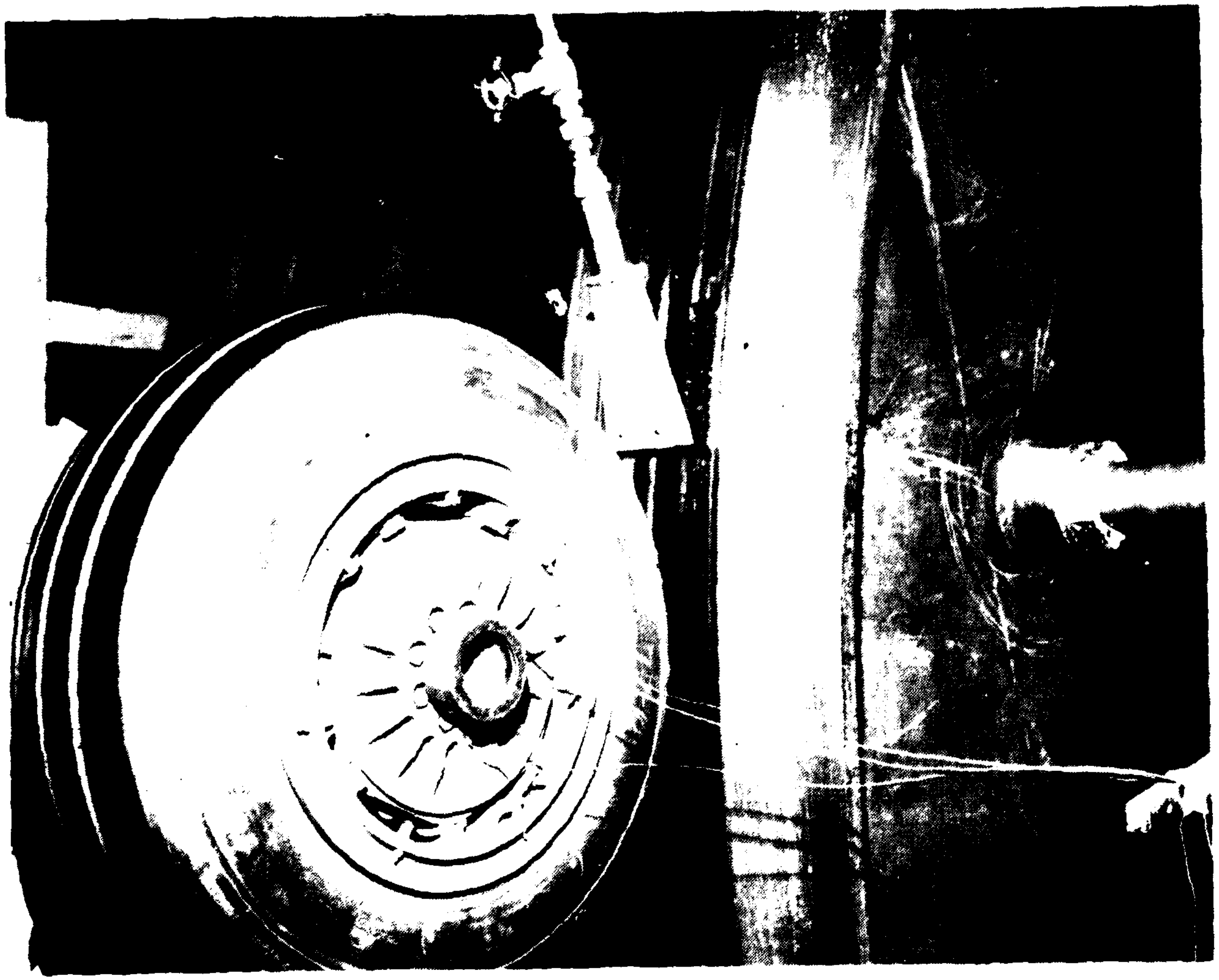


Figure 40. Variable Opening Nozzle High Speed Braking Tests, Dynamometer Set-Up

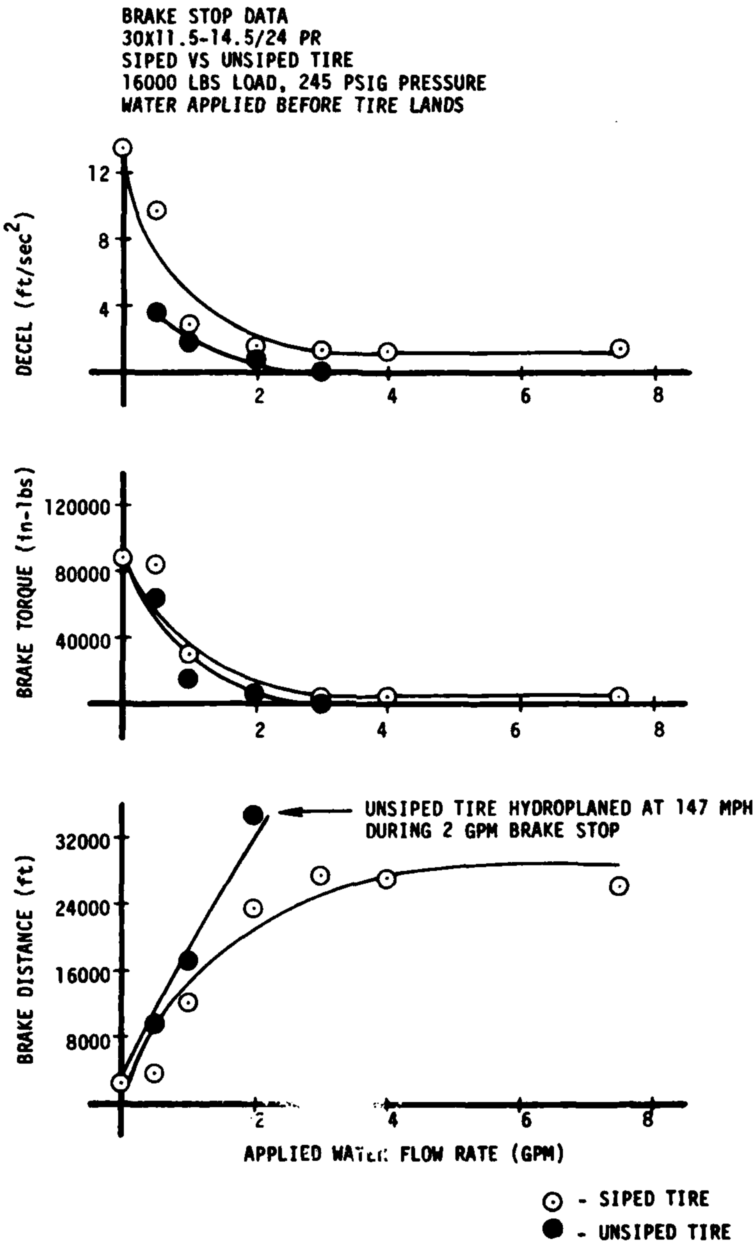


Figure 41. Brake Stop Data vs Water Flow Rate, Tire Code Number 1-R-2, Case I Tests

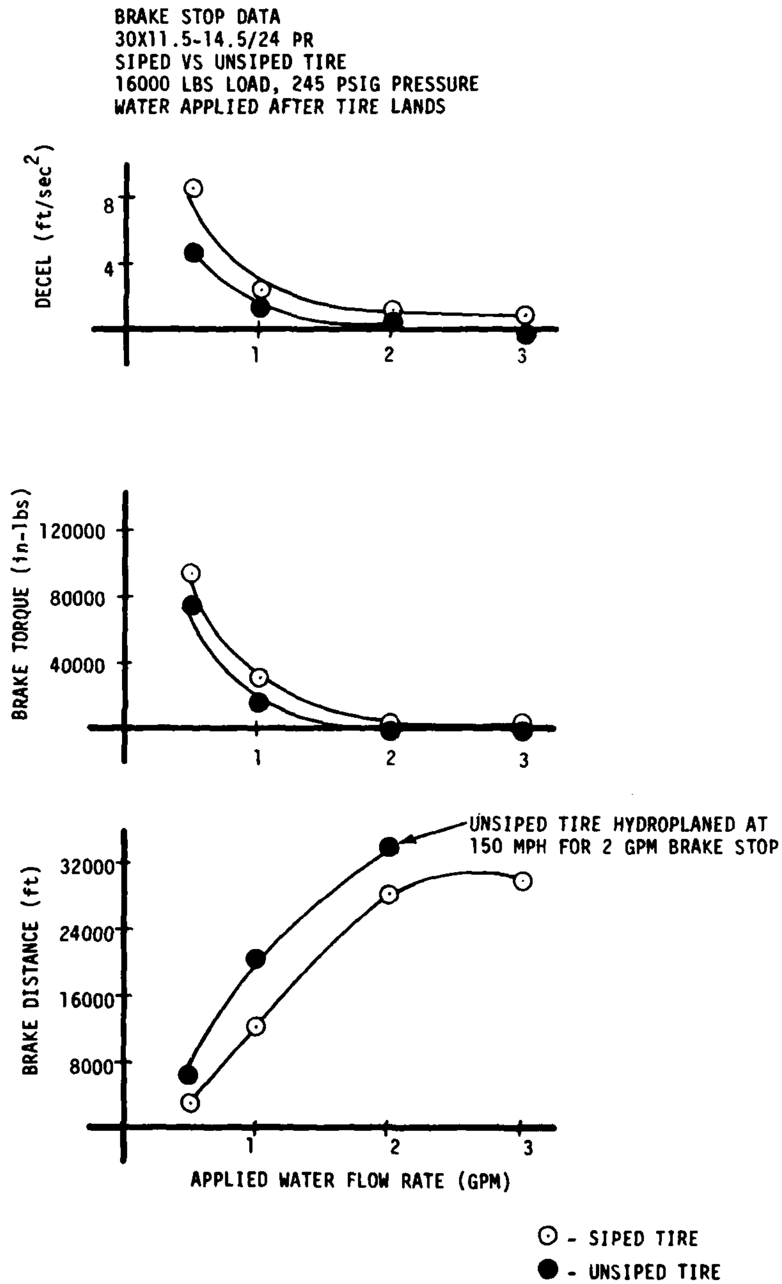


Figure 42. Brake Stop Data vs Water Flow Rate, Tire Code Number 1-R-2, Case II Tests

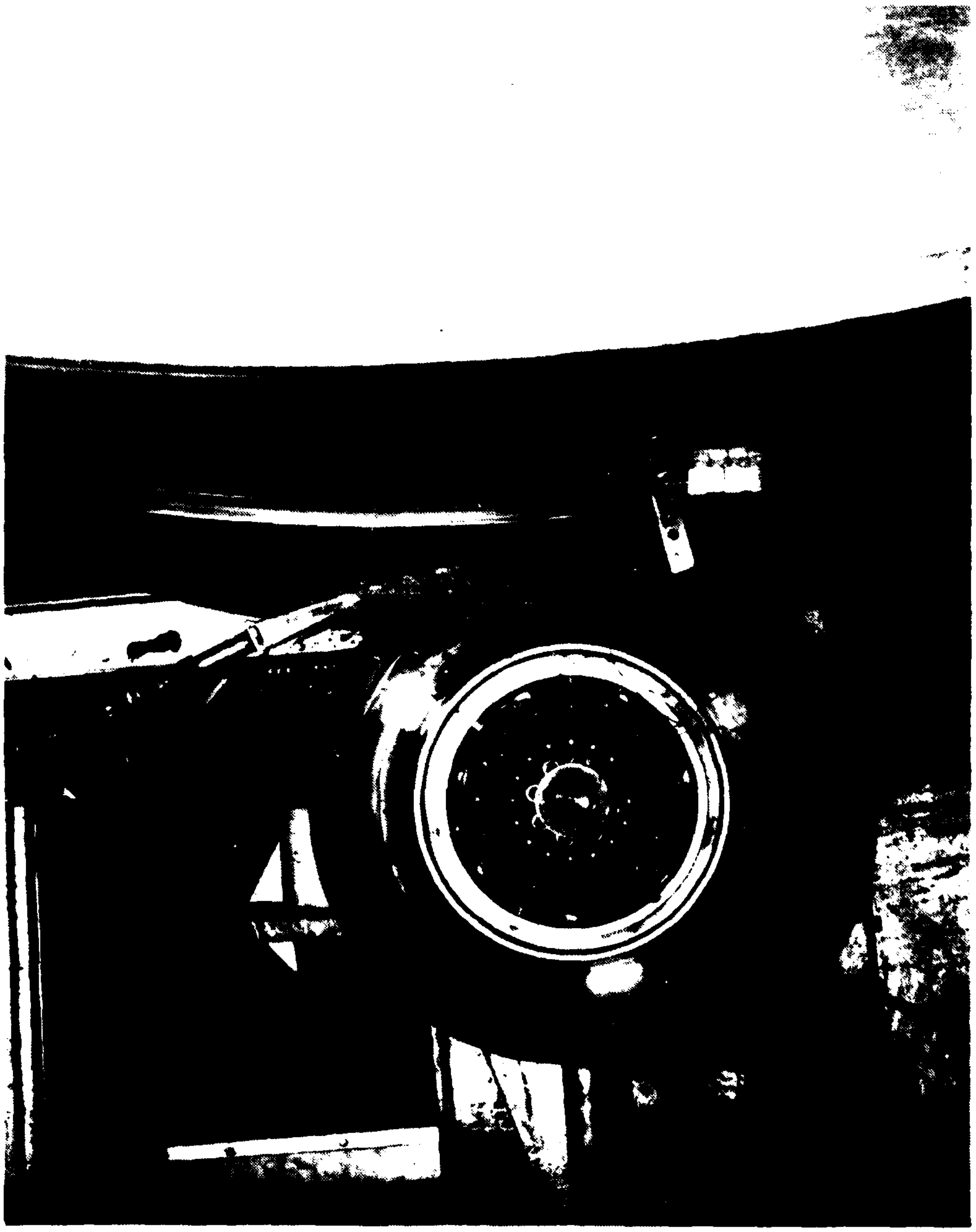


Figure 43. Application of Water to Flywheel, High Speed Braking Tests, 40 MPH - Test Speed

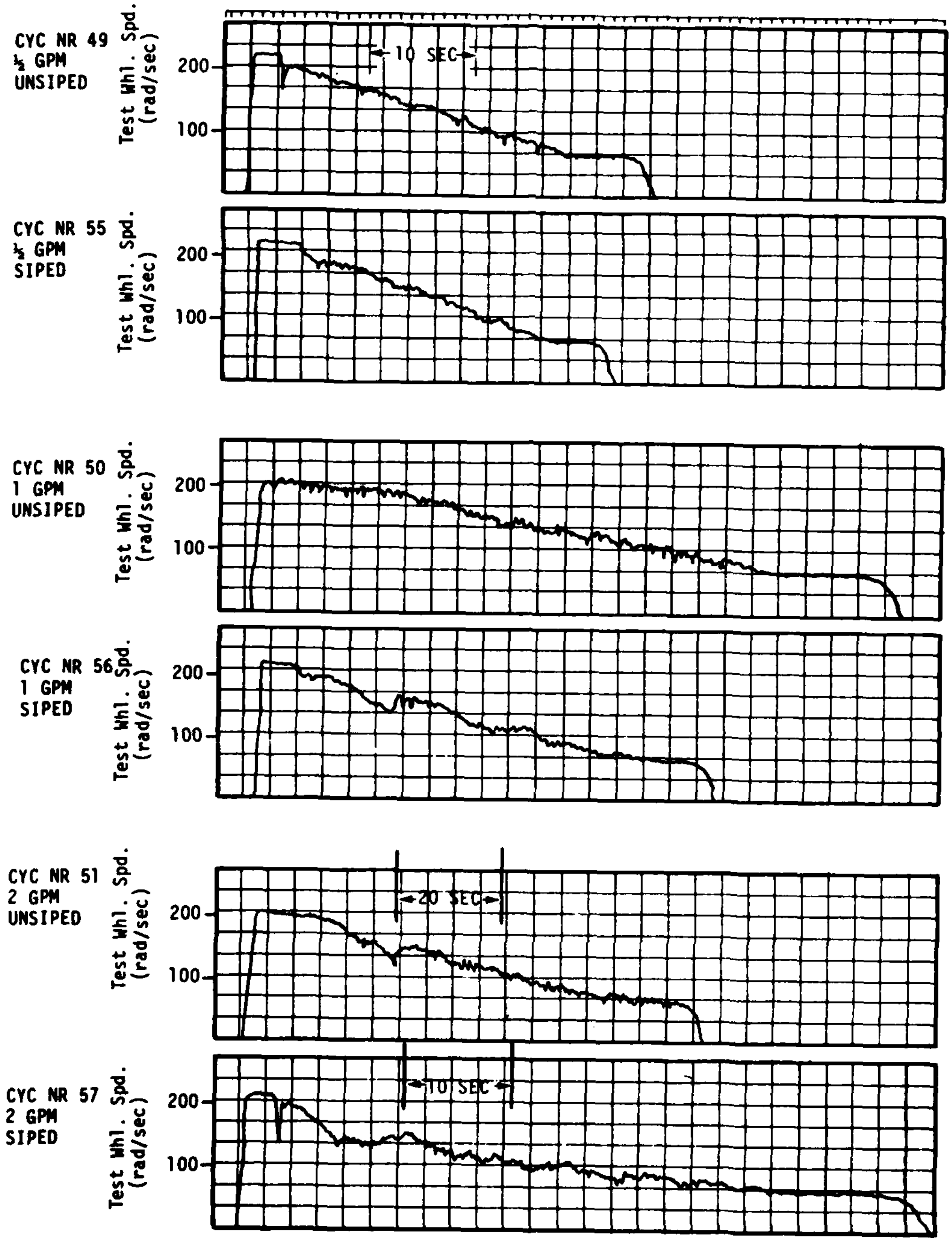


Figure 44. Tire Spin Up Comparison, Siped vs Unsiped, Tire Code Number 18-N, Tire Load 25,000 Lbs, Test Wheel/Tire Speed vs Time, 1/2, 1 and 2 GPM Water Flow Rates, Case 1-Water Applied Prior to Landing Tire

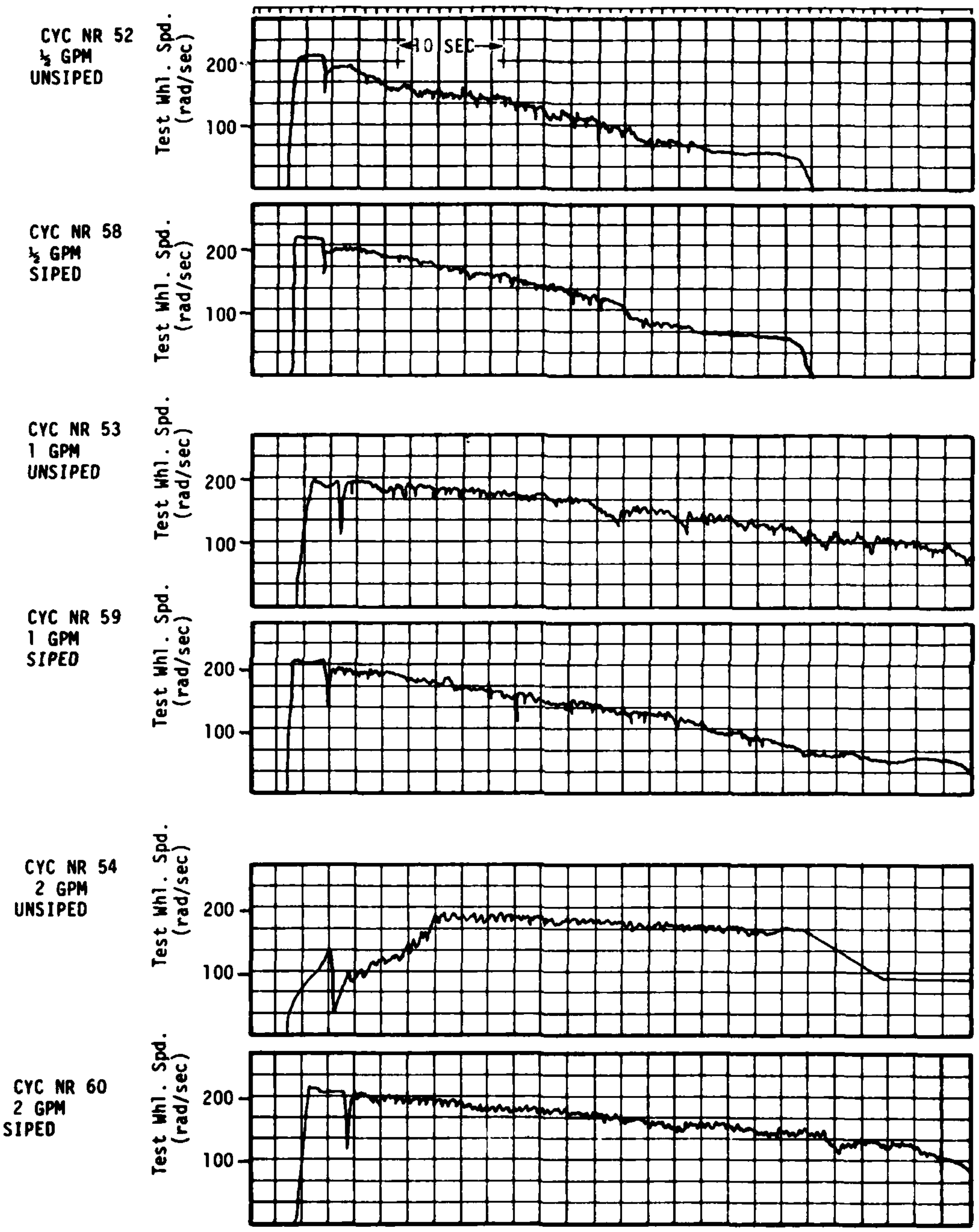


Figure 45. Tire Spin Up Comparison, Siped vs Unsiped, Tire Code Number 18-N, Tire Load 16,000 Lbs, Test Wheel/Tire Speed vs Time, 1/2, 1 and 2 GPM Water Flow Rates, Case 1-Water Applied Prior to Landing Tire

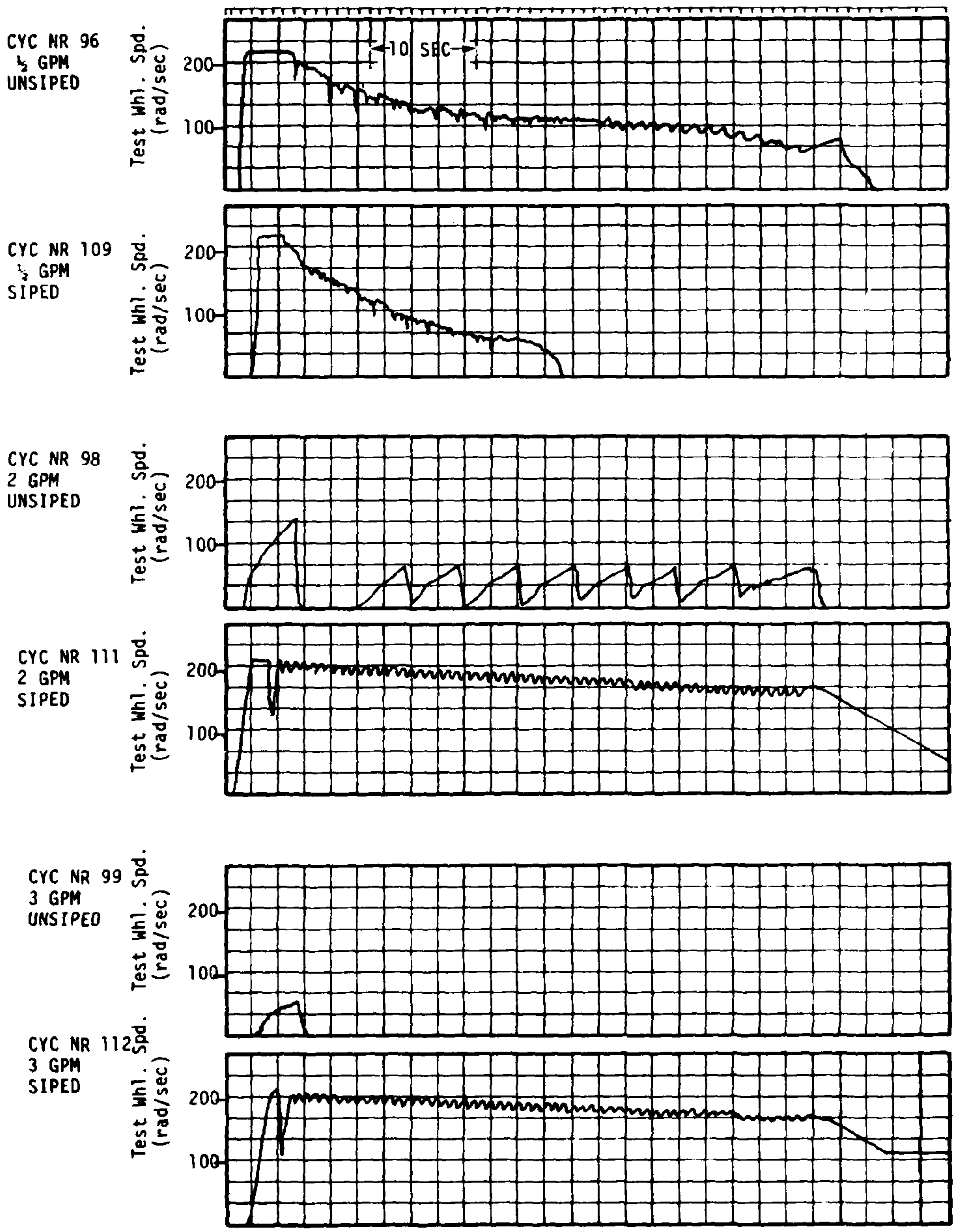


Figure 46. Tire Spin Up Comparison, Siped vs Unsiped, Tire Code Number 1-R-2, Tire Load 16,000 Lbs, Test Wheel/Tire Speed vs Time, 1/2, 2 and 3 GPM Water Flow Rates, Case 1-Water Applied Prior to Loading Tire

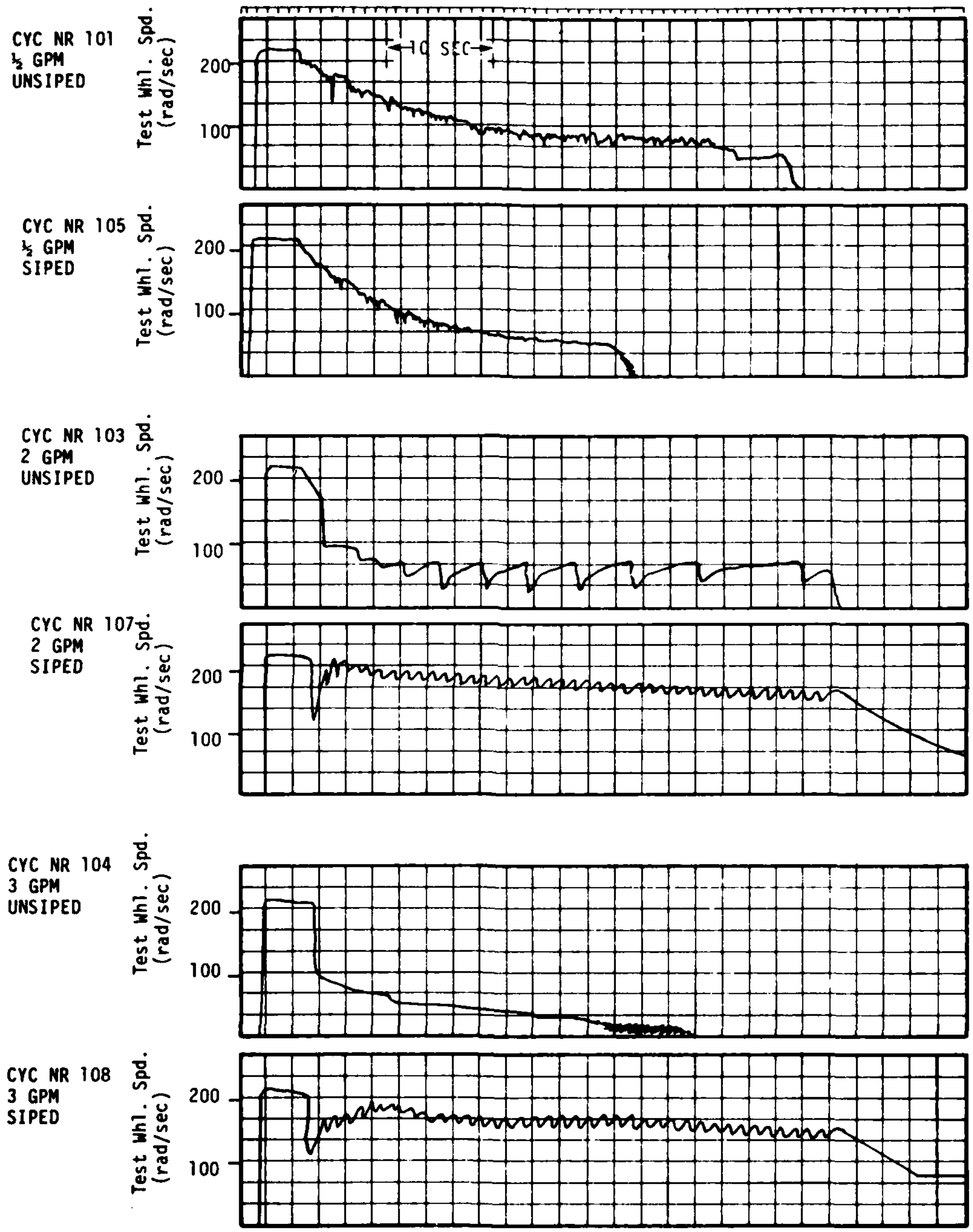


Figure 47. Tire Spin Up Comparison, Siped vs Unsiped, Tire Code Number 1-R-2, Tire Load 16,000 Lbs, Test Wheel/Tire Speed vs Time, 1/2, 2 and 3 GPM Water Flow Rates, Case 2-Water Applied After Loading Tire

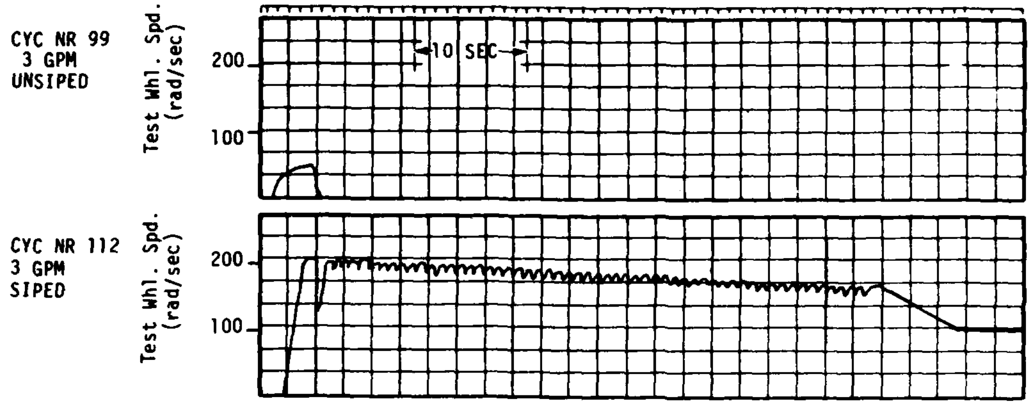


Figure 48. Tire Spin Up Comparison, Siped vs Unsiped, Tire Code Number 1-R-2, Tire Load 16,000 Lbs, Test Wheel/Tire Speed vs Time, 3 GPM Water Flow Rate, Case 1-Water Applied Prior to Landing Tire

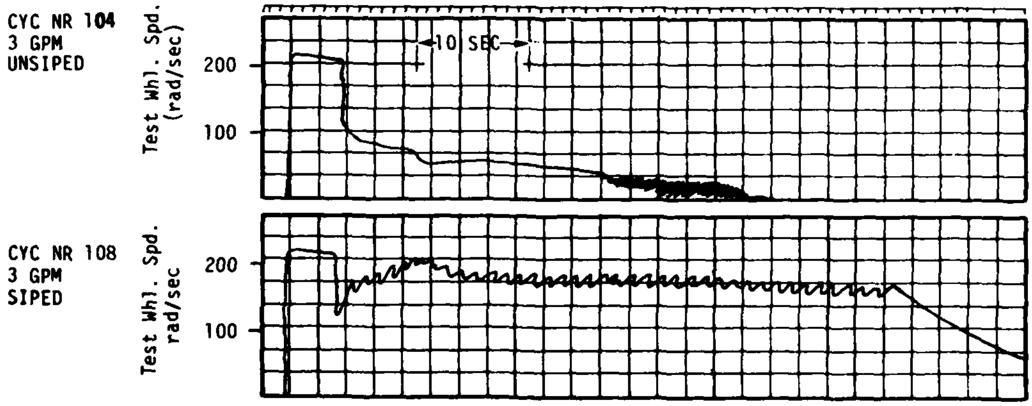


Figure 49. Tire Spin Up Comparison, Siped vs Unsiped, Tire Code Number 1-R-2, Tire Load 16,000 Lbs, Test Wheel/Tire Speed vs Time, 3 GPM Water Flow Rate, Case 2-Water Applied After Loading Tire

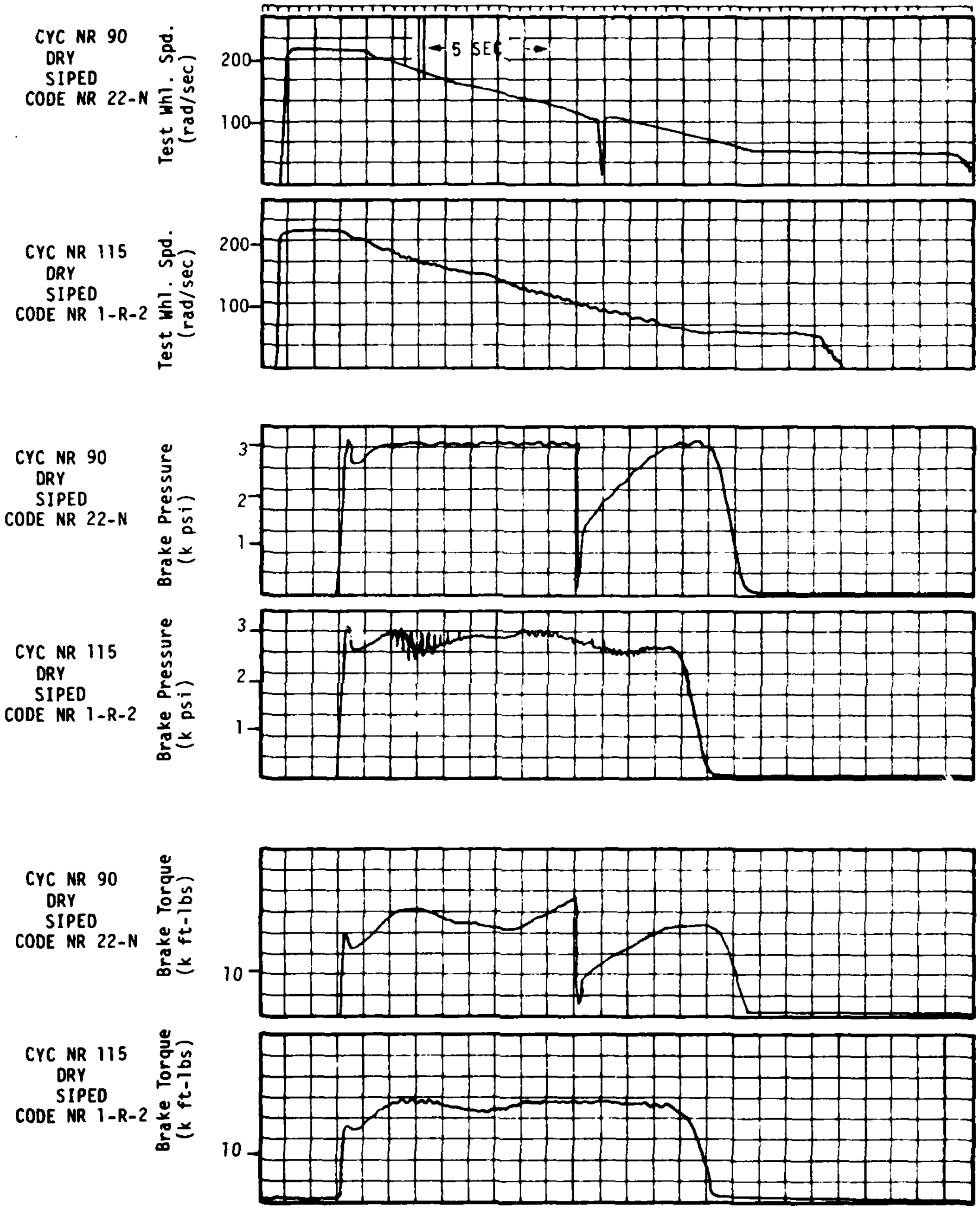


Figure 50. Dry Brake Test Runs Tires Code Numbers 22-N and 1-R-2 Tire Load, 16,000 Lbs (Test Wheel/Tire Speed, Brake Pressure and Brake Torque vs Time)

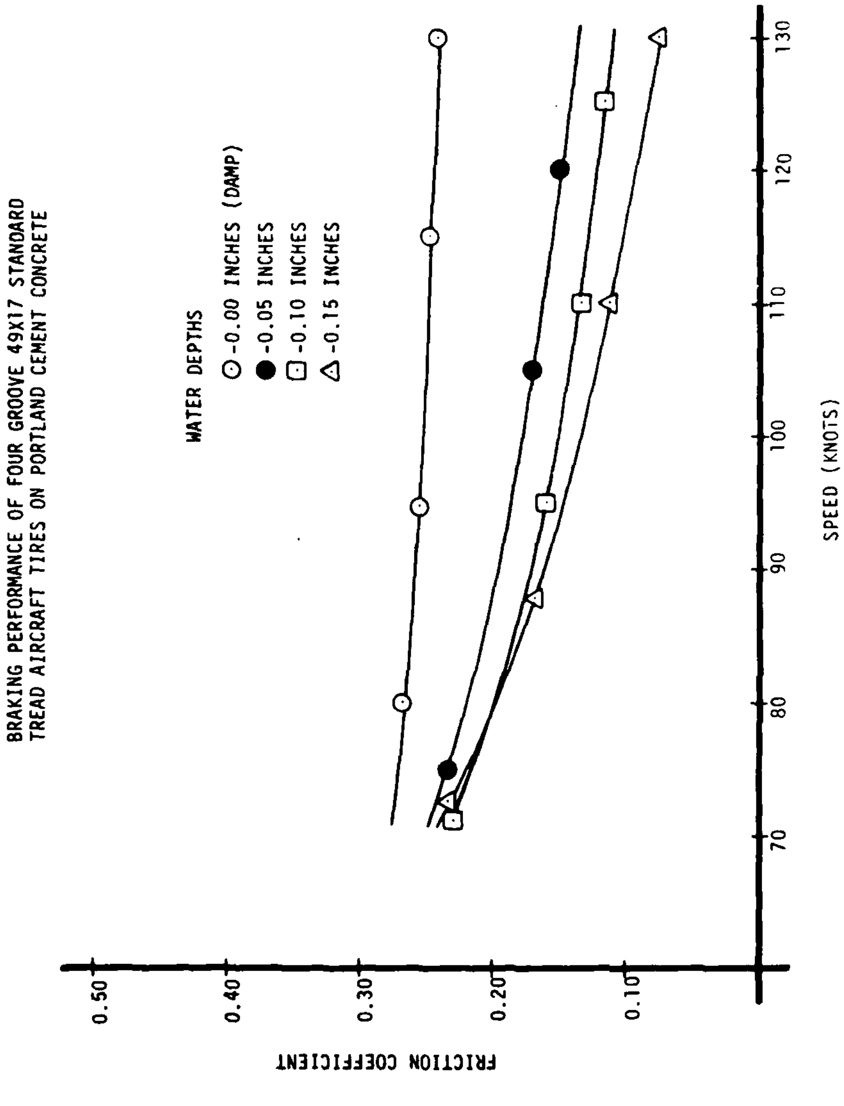


Figure 51. Friction Coefficient vs Speed, Wet Track Tests, KC-135 Tire - Standard Tread

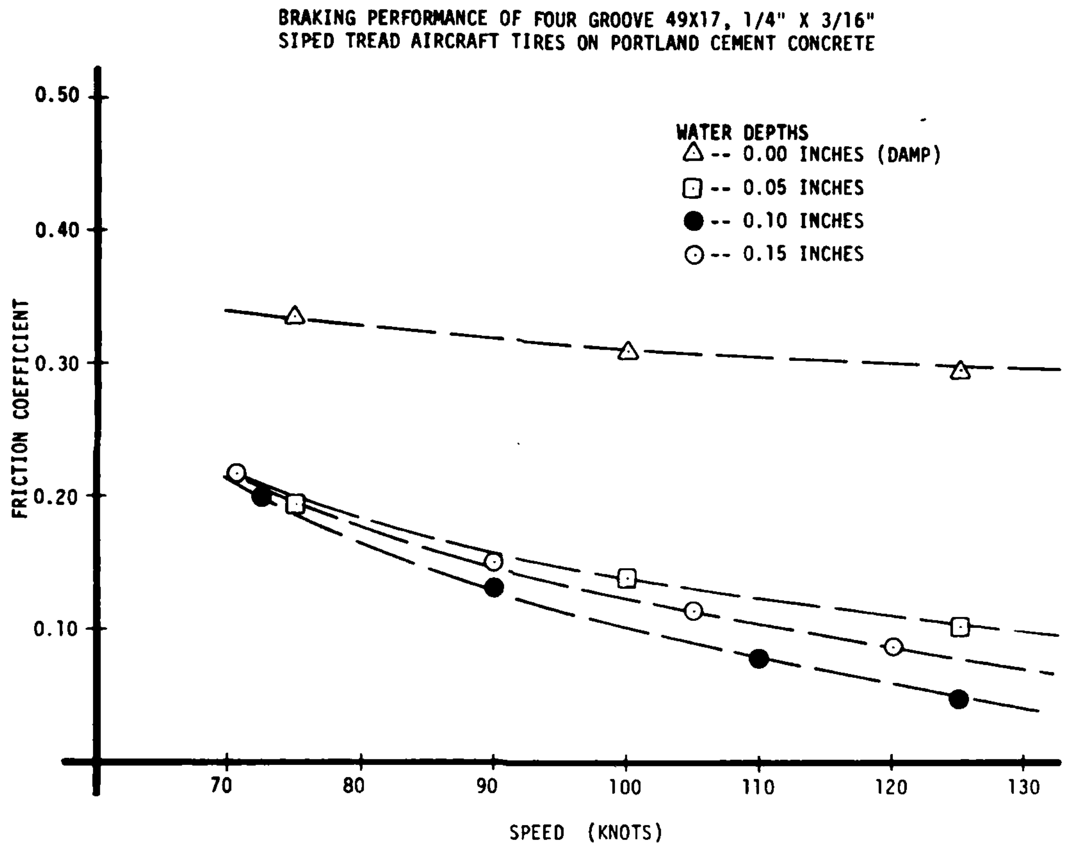


Figure 52. Friction Coefficient vs Speed, Wet Track Tests, KC-135 Tire - 1/4 Inch Deep Sipe

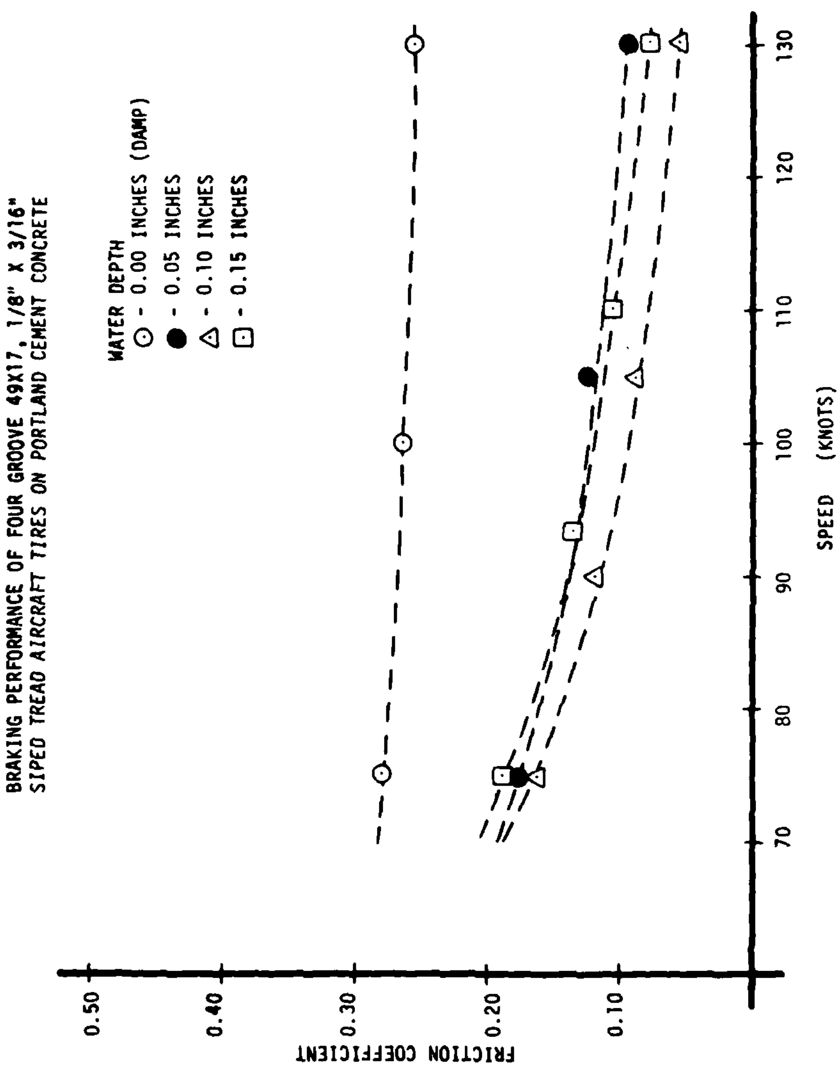


Figure 53. Friction Coefficient vs Speed, Wet Track Tests, KC-135 Tire - 1/8 Inch Deep Sipe

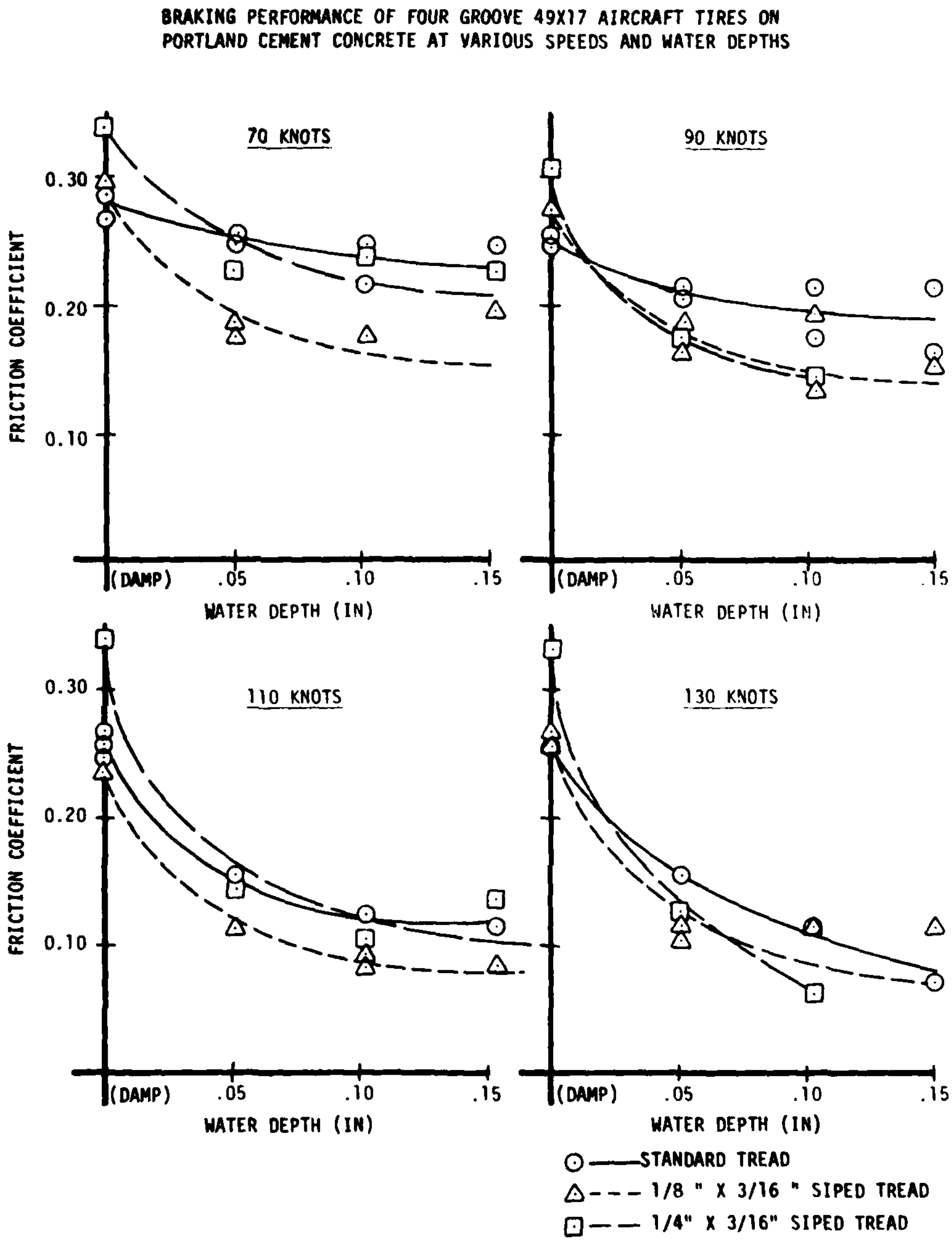


Figure 54. Friction Coefficient vs Water Depth, Wet Track Tests, KC-135 Tire

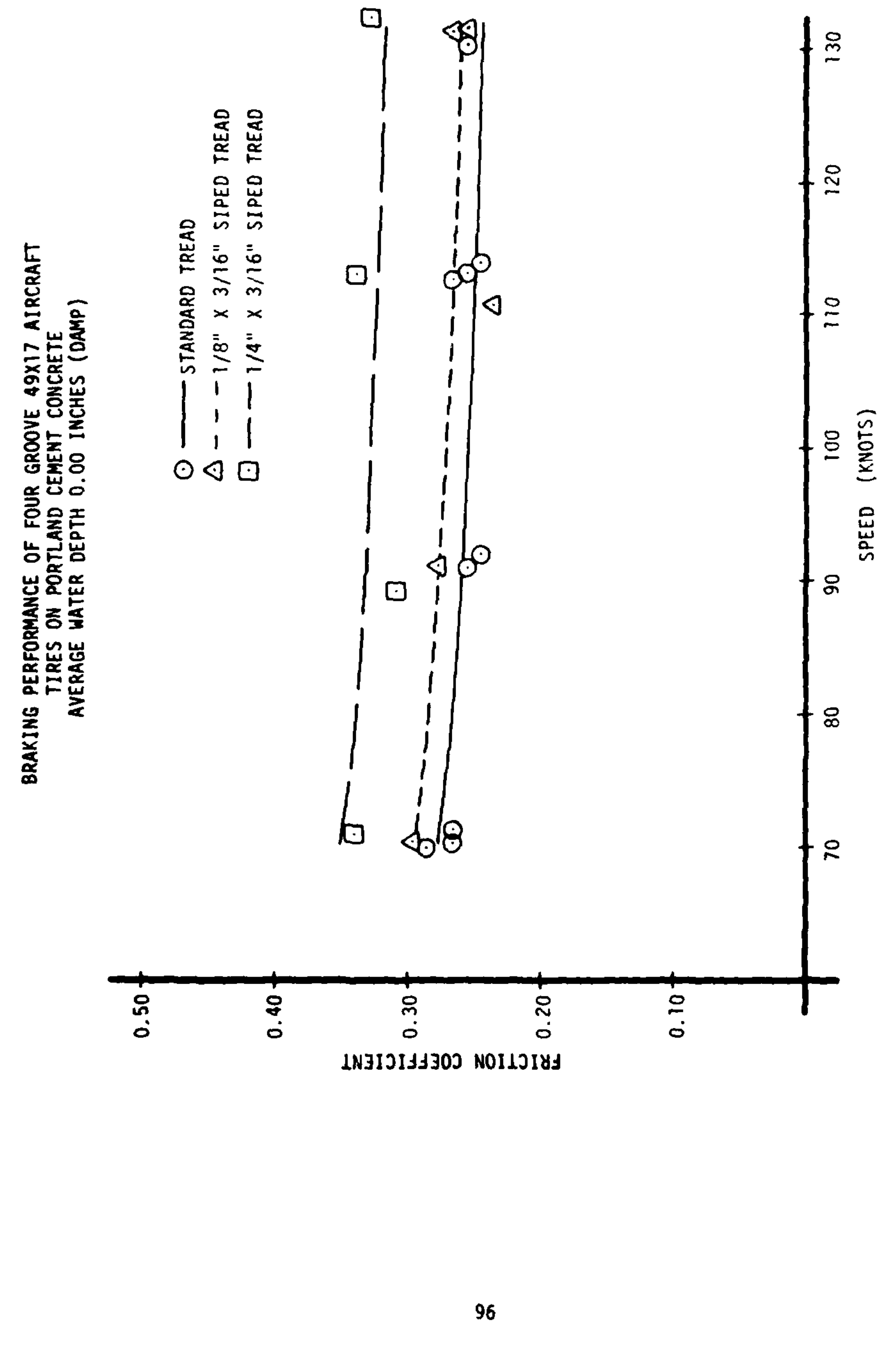


Figure 55. Friction Coefficient vs Speed, Wet Track Tests, KC-135 Tire, Water Depth (Damp)

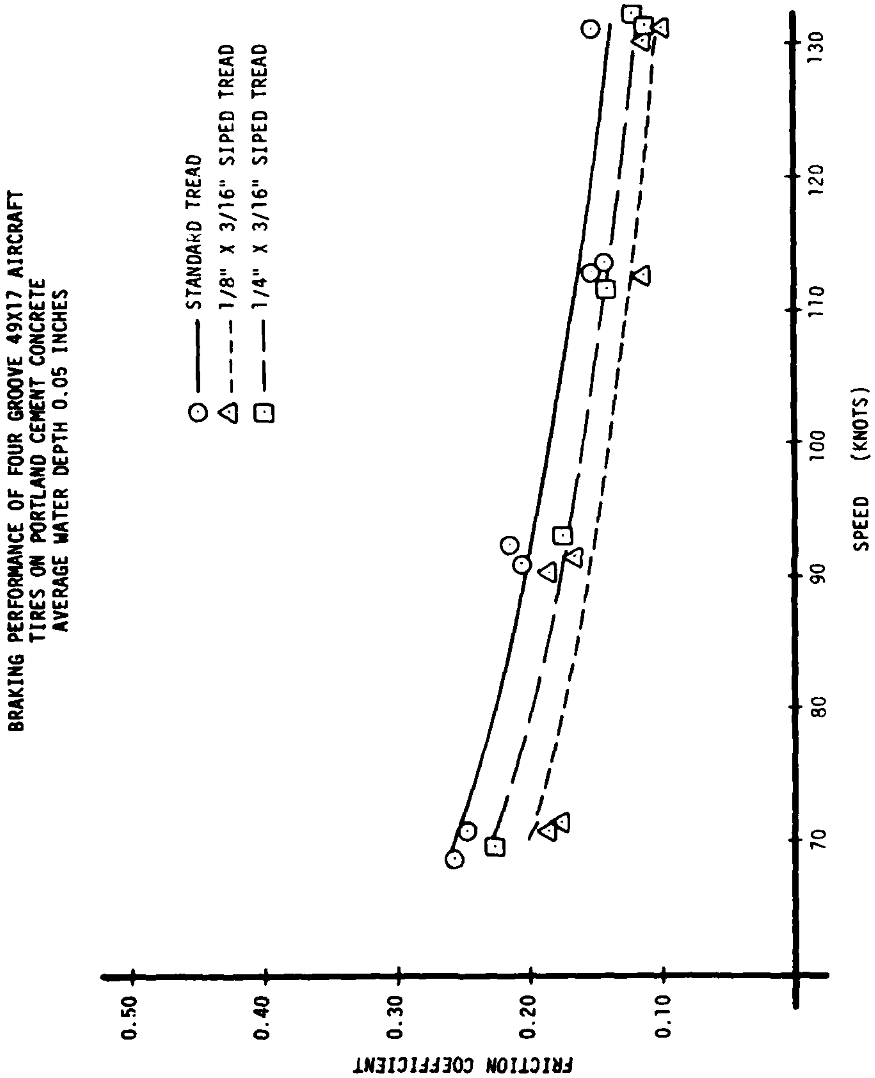


Figure 56. Friction Coefficient vs Speed, Wet Track Tests, KC-135 Tire, Water Depth (0.05 Inch)

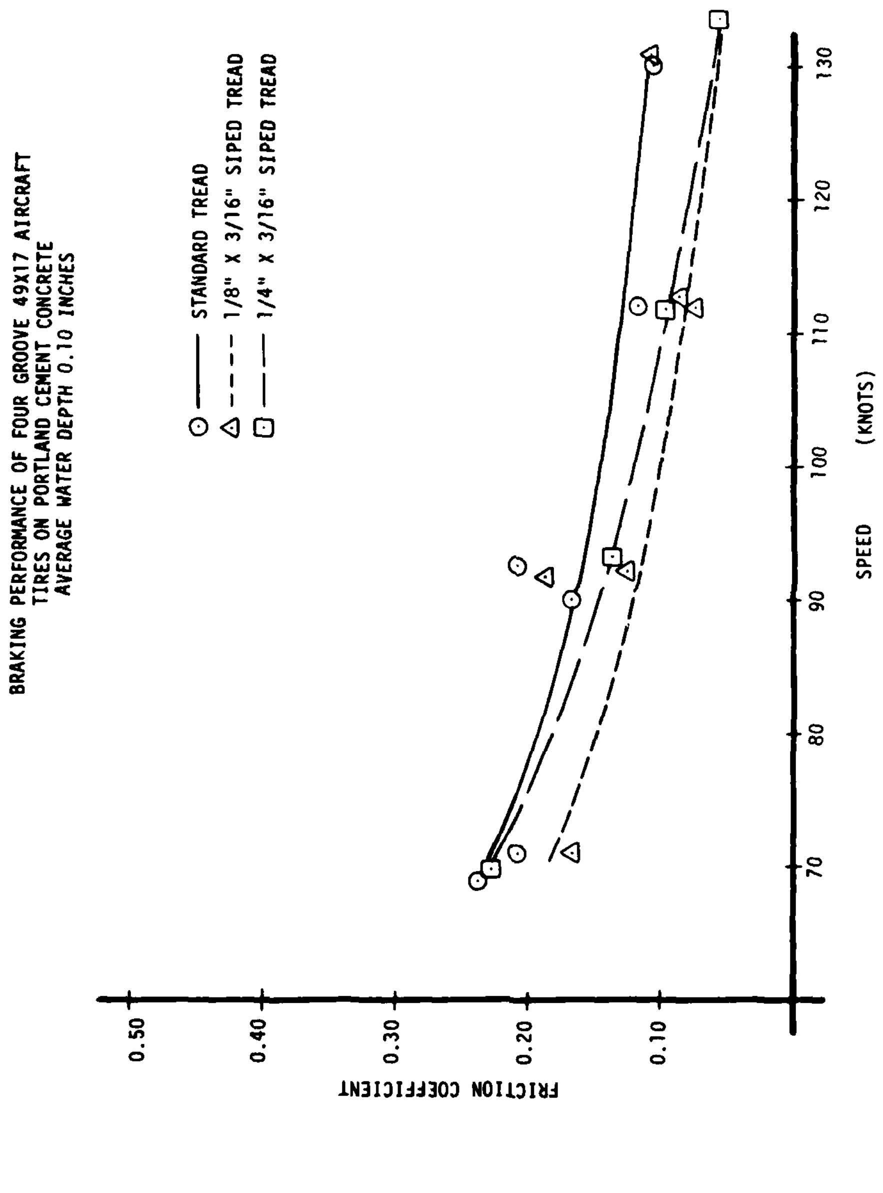


Figure 57. Friction Coefficient vs Speed, Wet Track Tests KC-135 Tire, Water Depth (0.10 Inch)

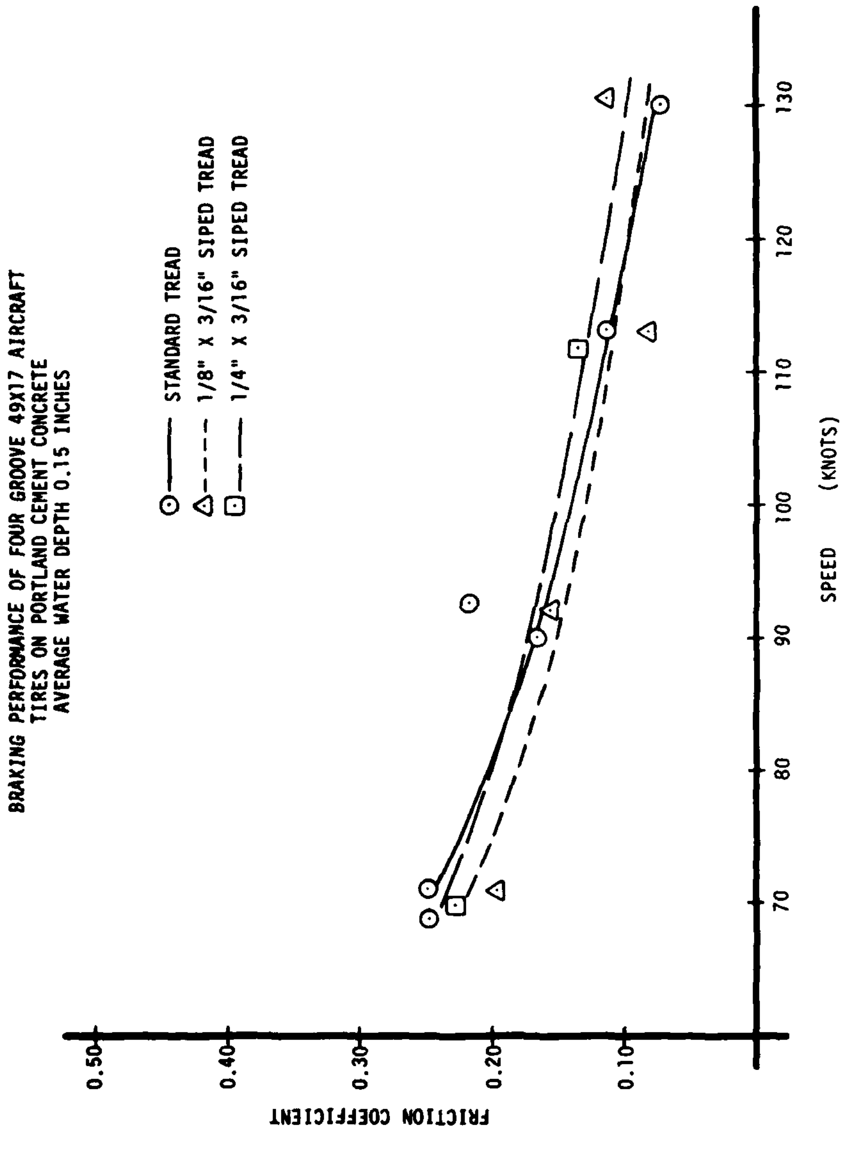


Figure 58. Friction Coefficient vs Speed, Wet Track Tests, KC-135 Tire, Water Depth (0.15 Inch)

APPENDIX C

ANALOG TRACES

HIGH SPEED BRAKE ANTI-SKID STOPS

192 INCH DYNAMOMETER

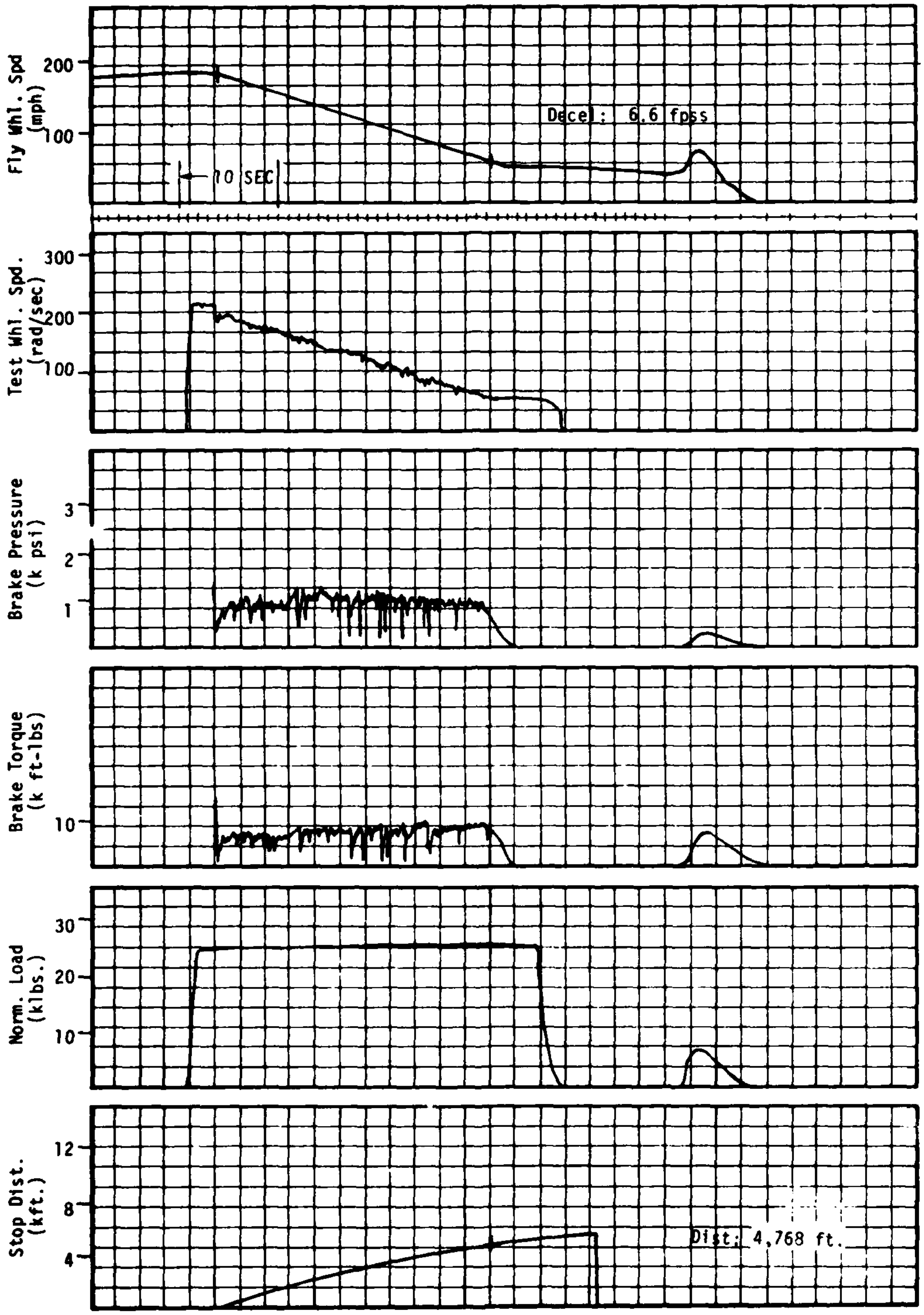


Figure C1. S/N0870(18-N), Cyc. 49, 0.5 gpm

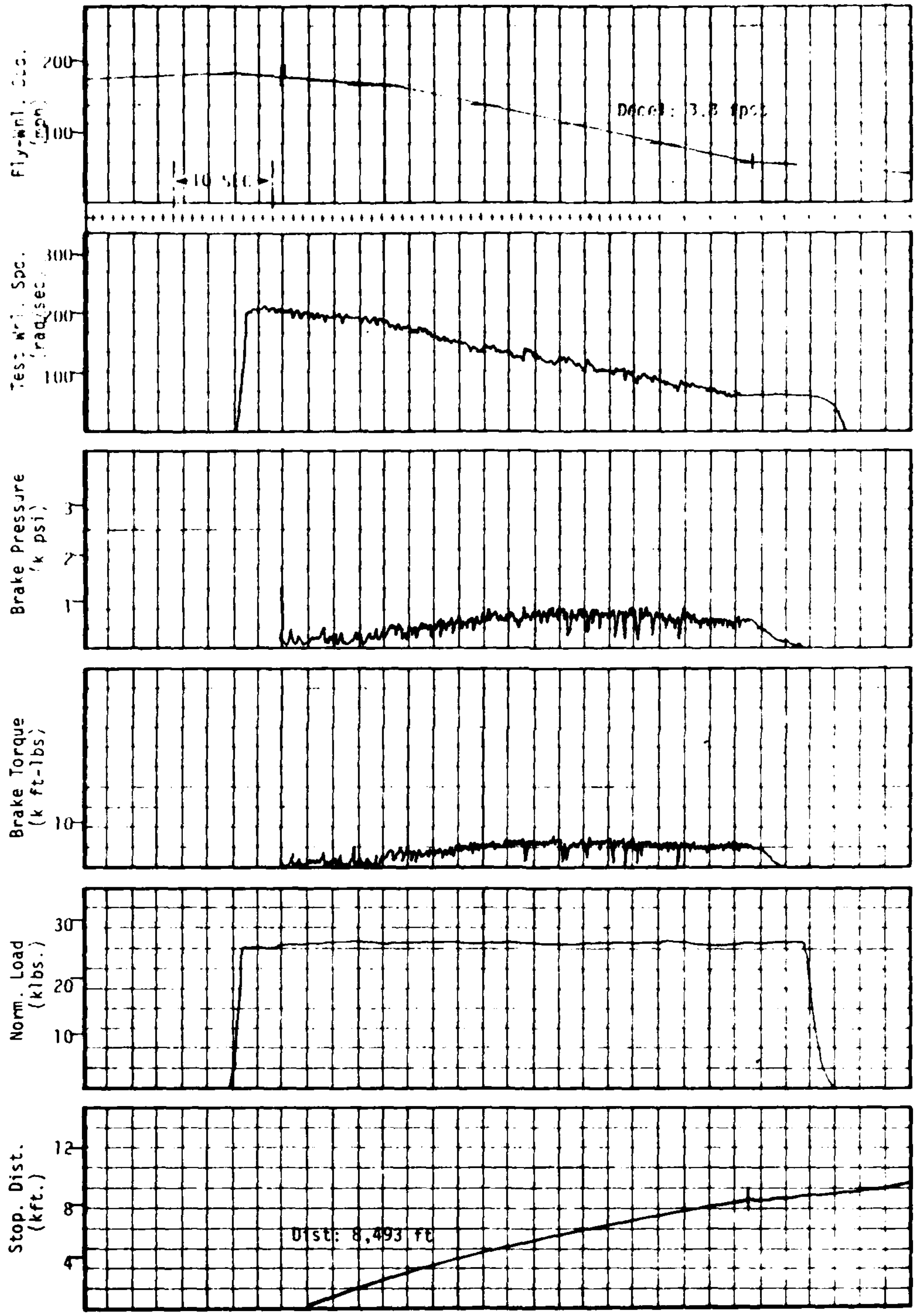


Figure C2. S/N0870(18-N), Cyc. 50, 1.0 gpm

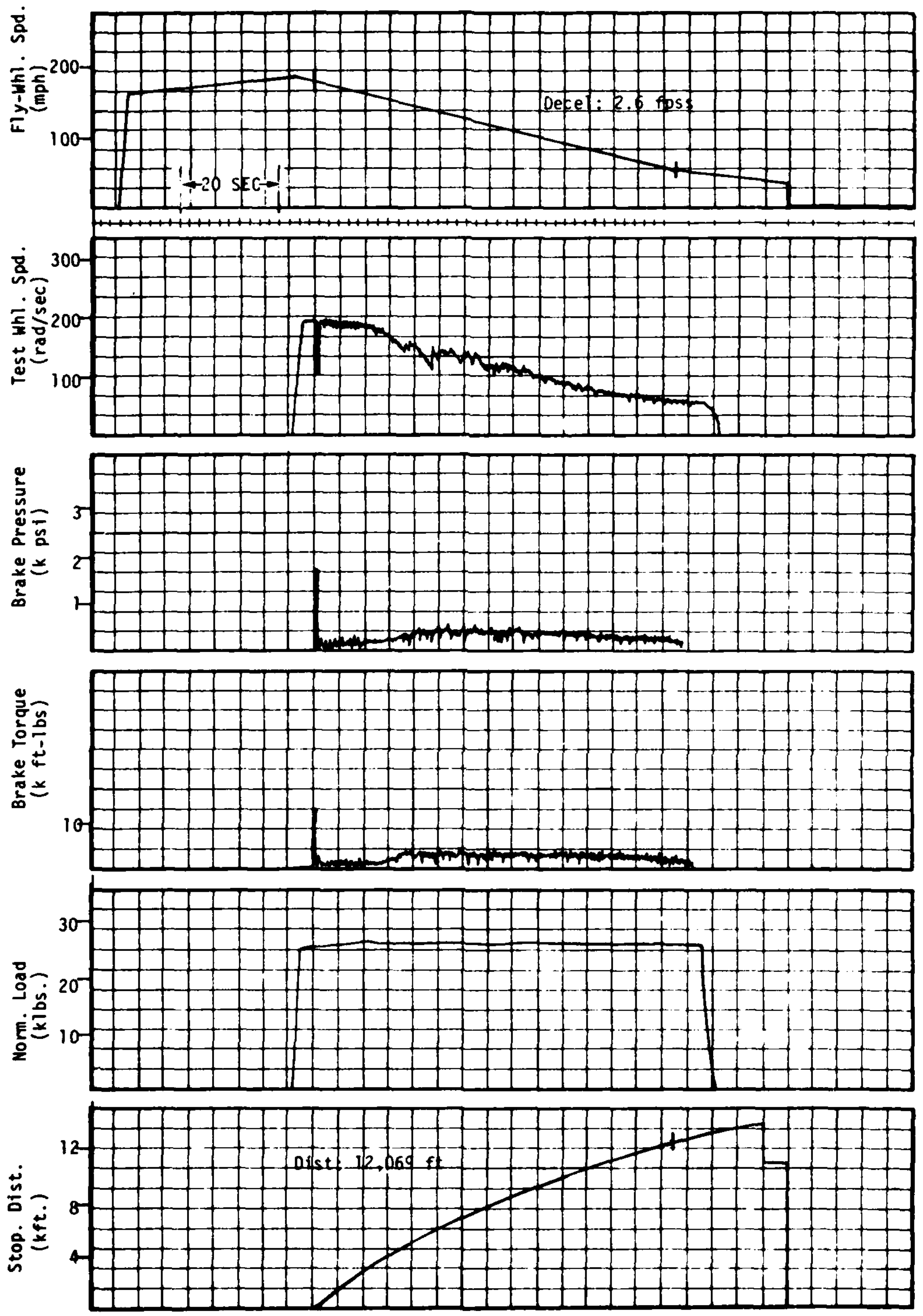


Figure C3. S/N0870(18-N), Siped N/A Cyc. 51, 2.0 gpm

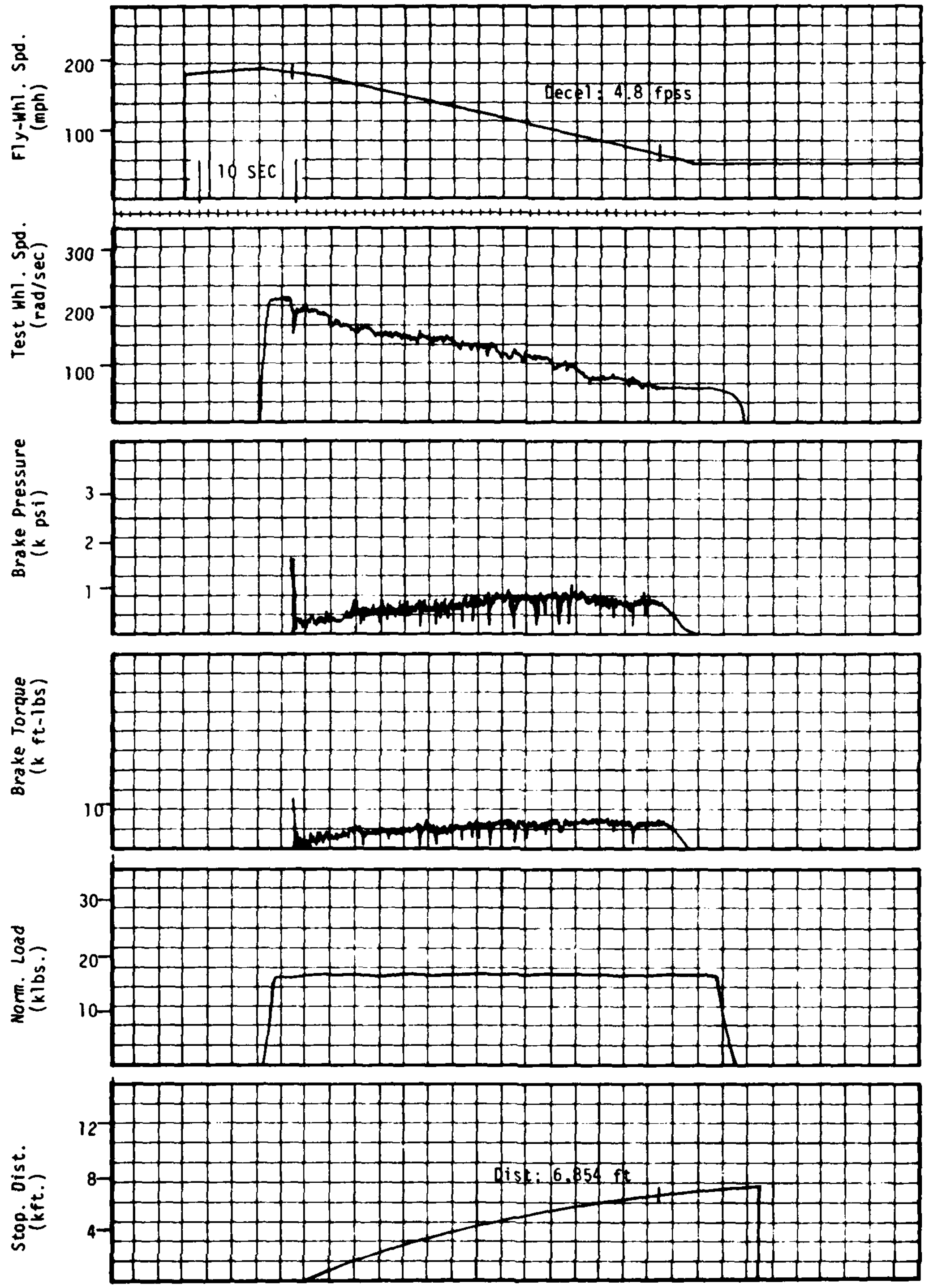


Figure C4. S/N0870(18-N), Siped N/A Cyc. 52, 0.5 gpm

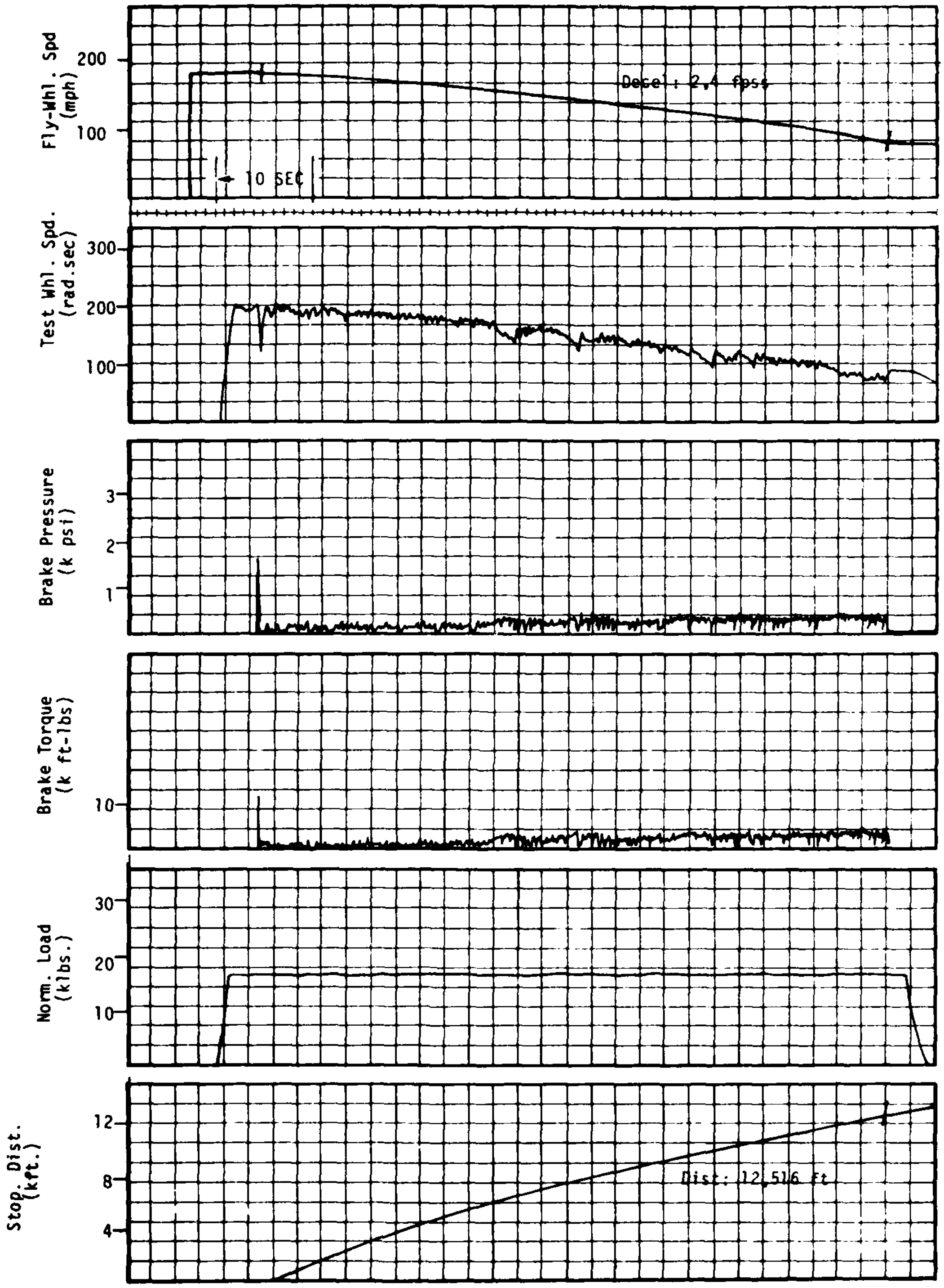


Figure C5. S/N0870(18-N), Siped N/A Cyc. 53, 1.0 gpm

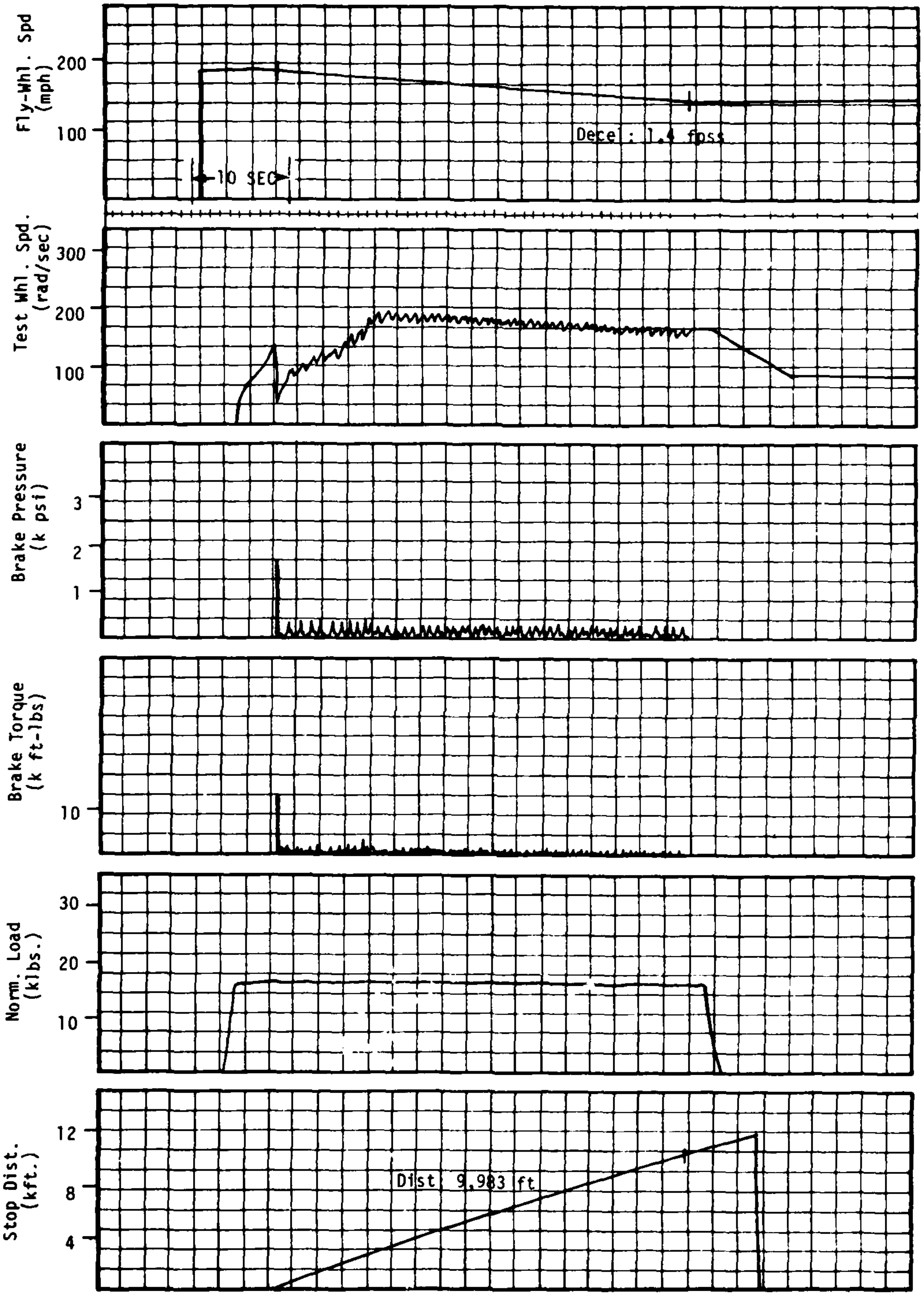


Figure C6. S/N0870(18-N), Siped N/A Cyc. 54, 2.0 gpm

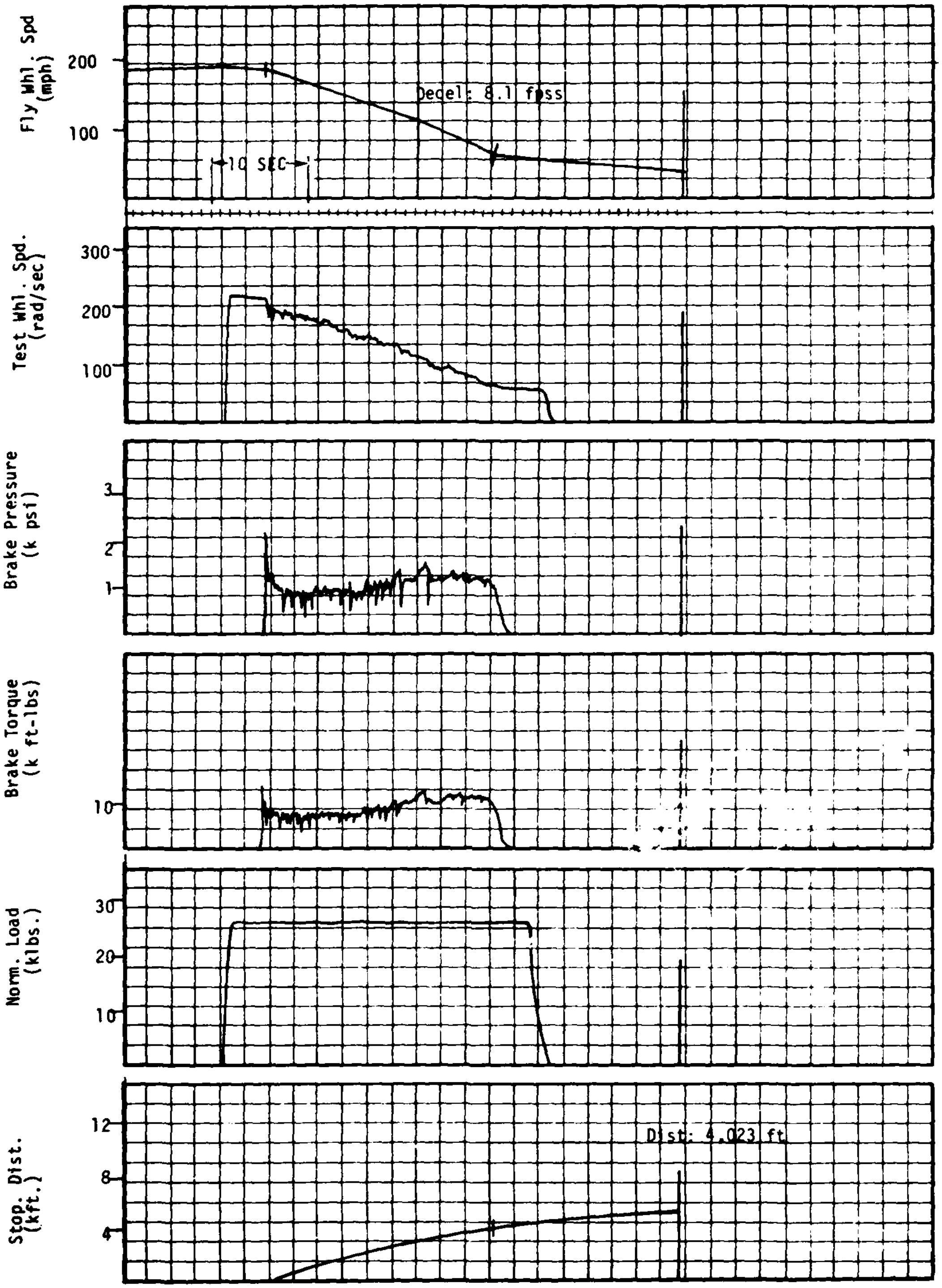


Figure C7. S/N0870(18-N), Siped 3/16" X 8/32", Cyc. 55, 0.5 gpm

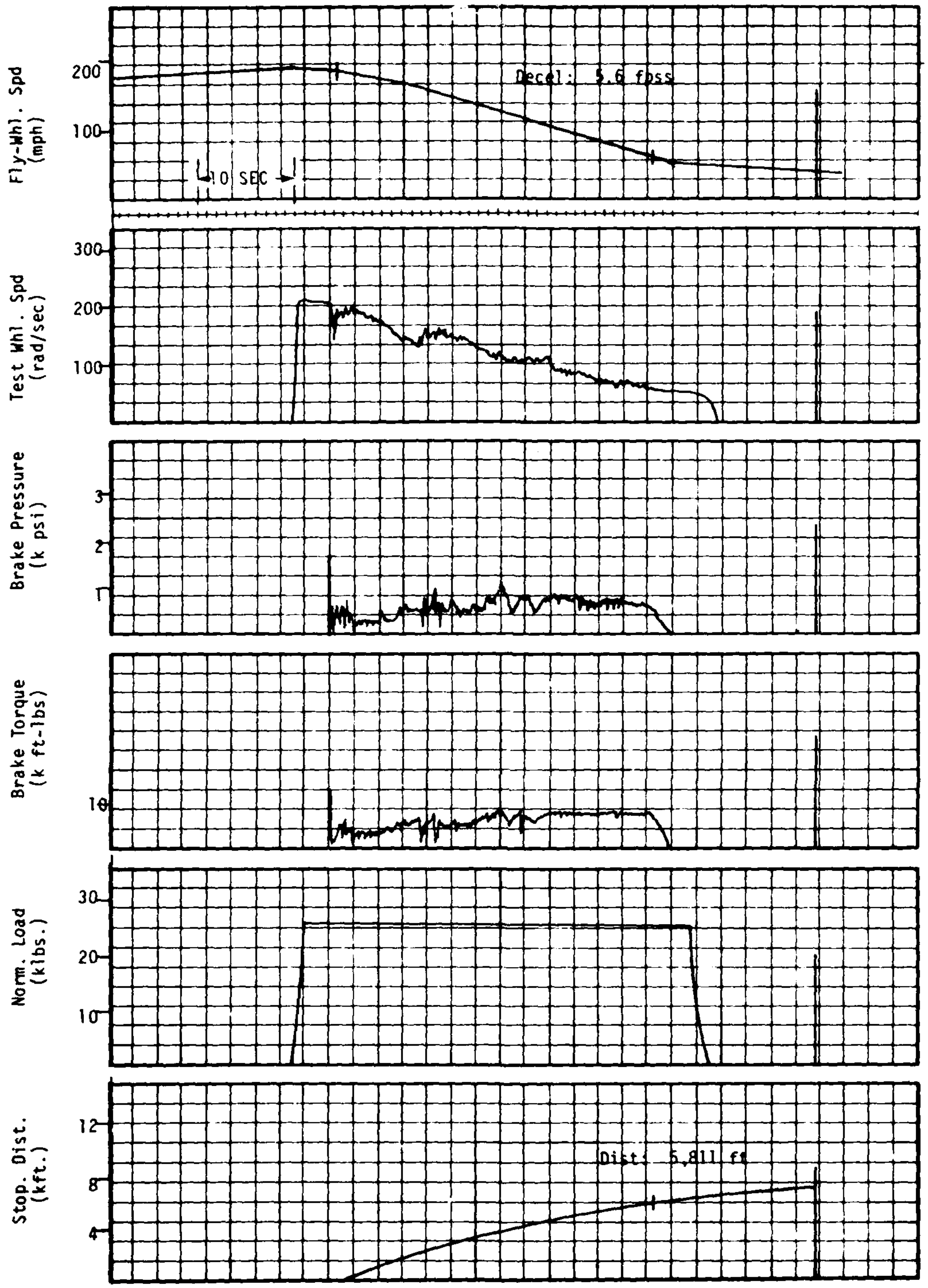


Figure C8. S/N0870(18-N), Siped 3/16" X 8/32", Cyc. 56, 1.0 gpm

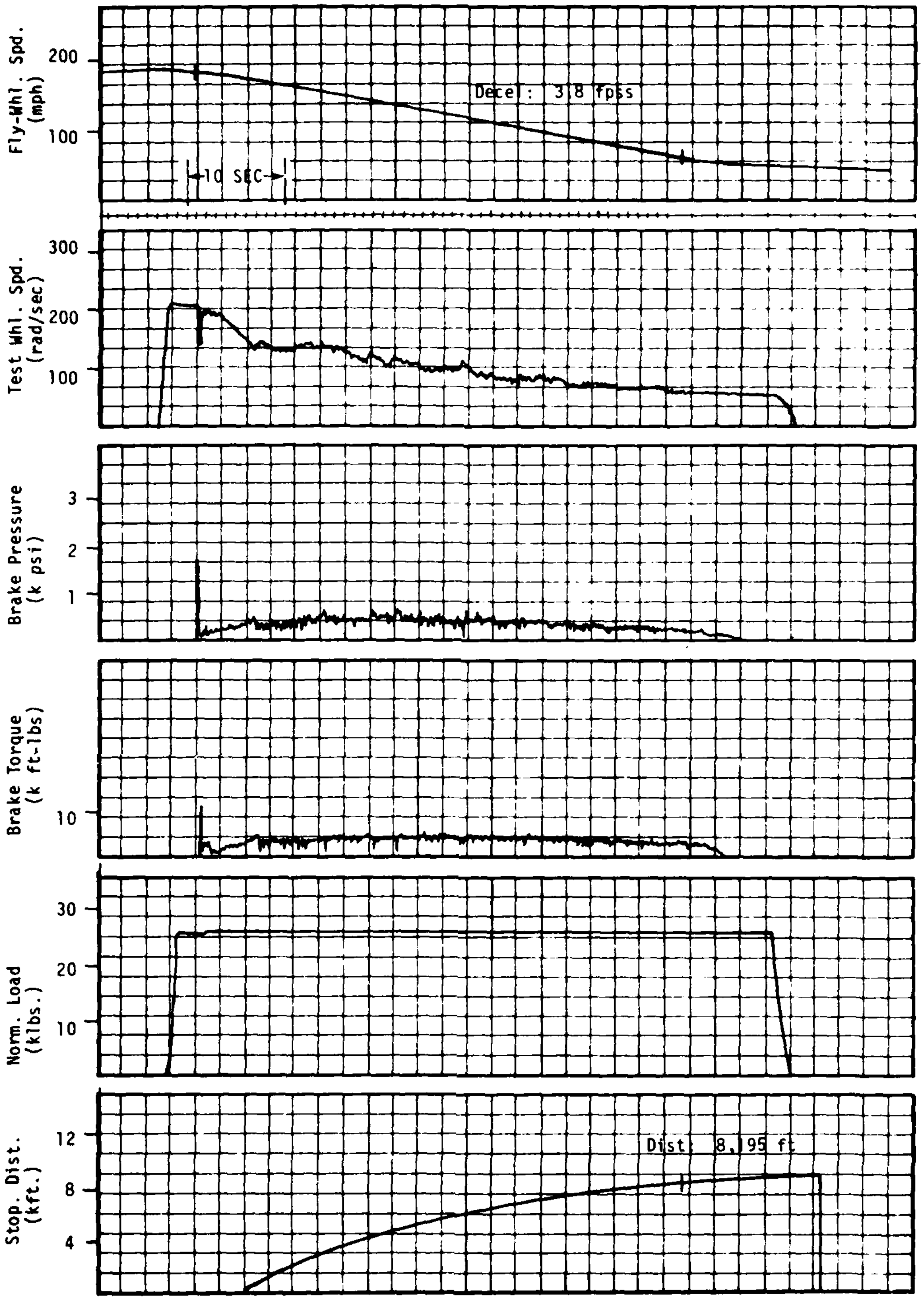


Figure C9. S/N0870(18-N), Siped 3/16" X 8/32", Cyc. 57, 2.0 gpm

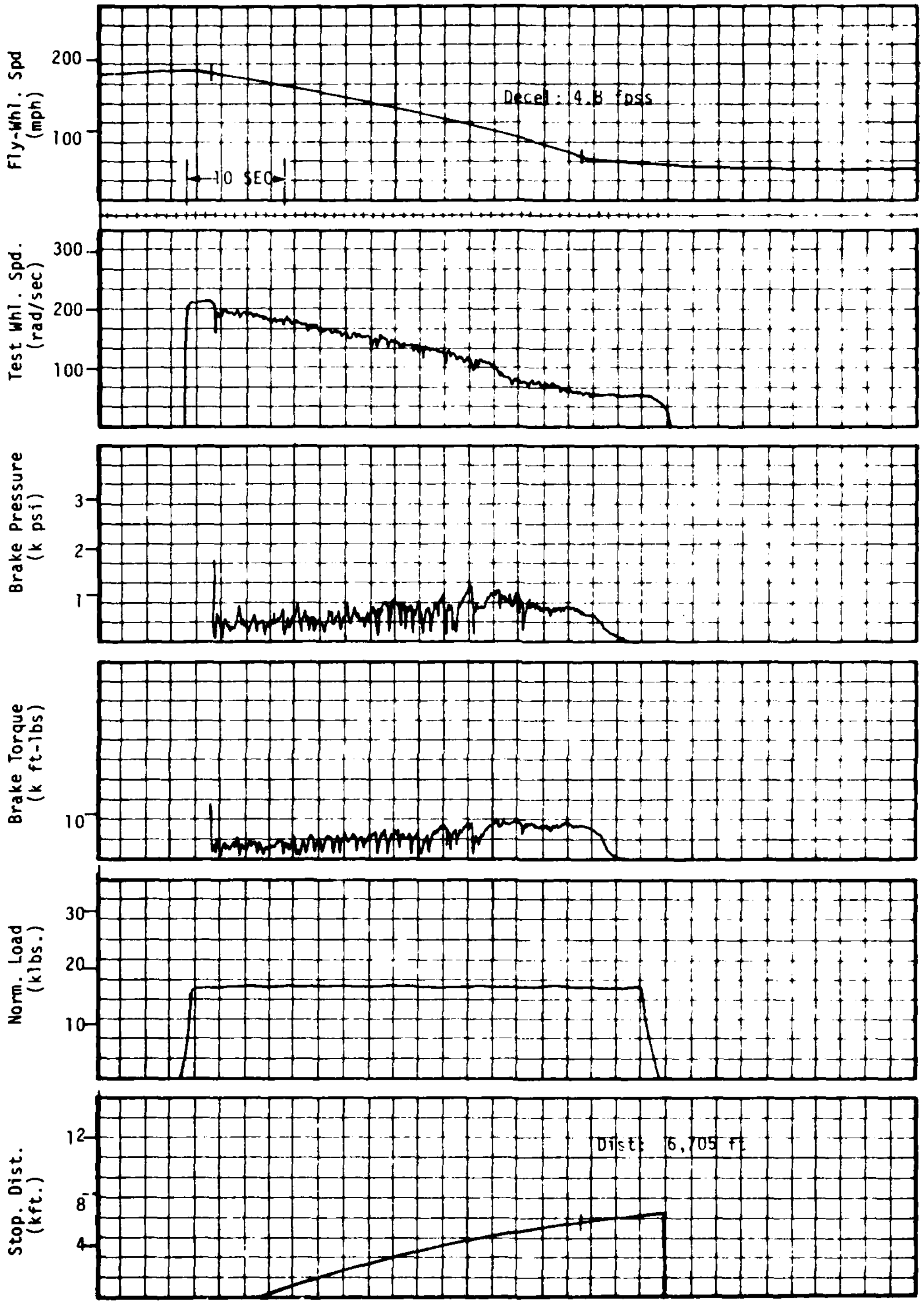


Figure C-10. S/N0870(18-N), Siped 3/16" X 8/32", Cyc. 58, 0.5 gpm

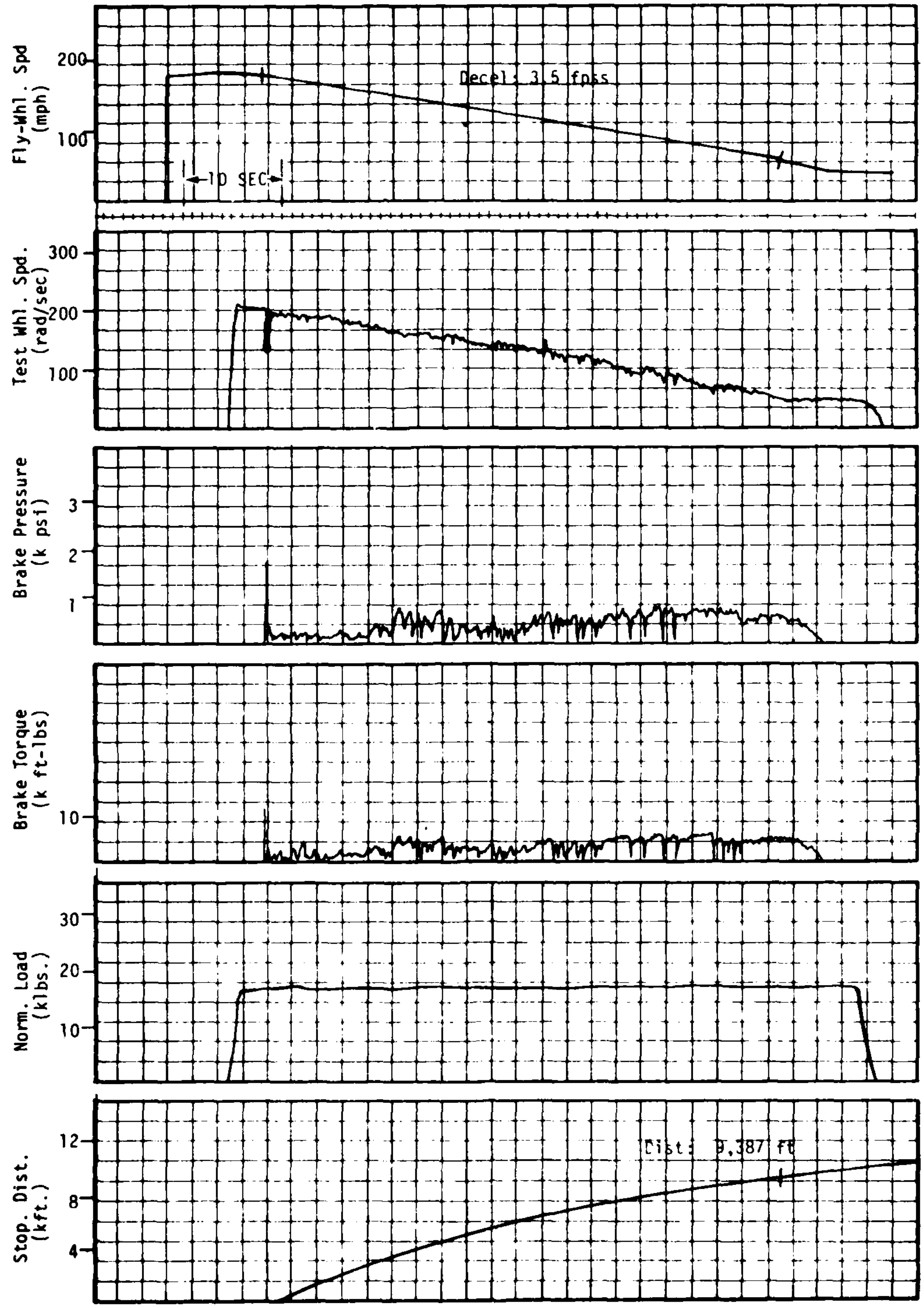


Figure C-11. S/N0870(18-N), Siped 3/16" X 8/32", Cyc. 59, 1.0 gpm

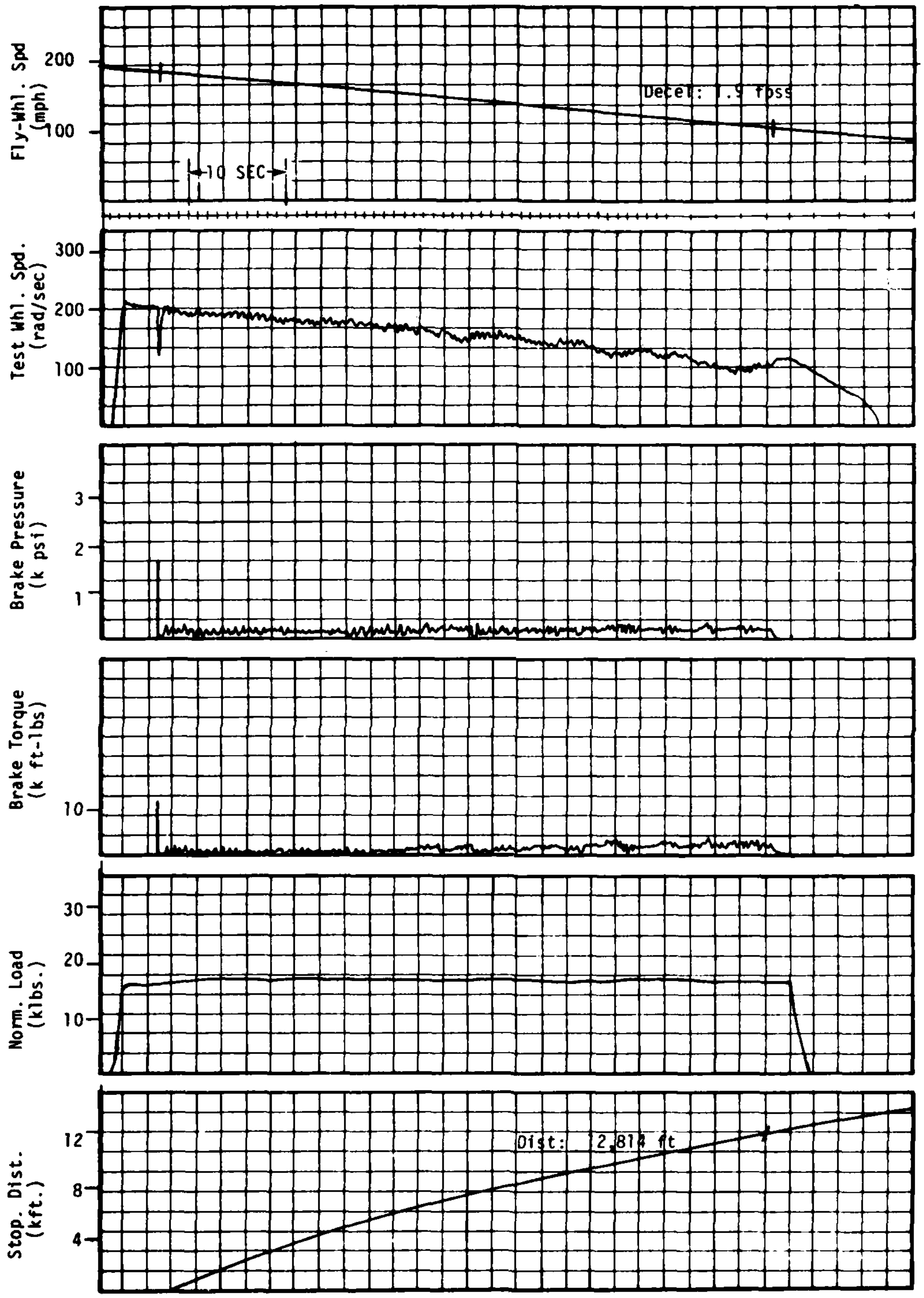


Figure C-12. S/N0870(18-N), Siped 3/16" X 8/32", Cyc. 60, 2.0 gpm

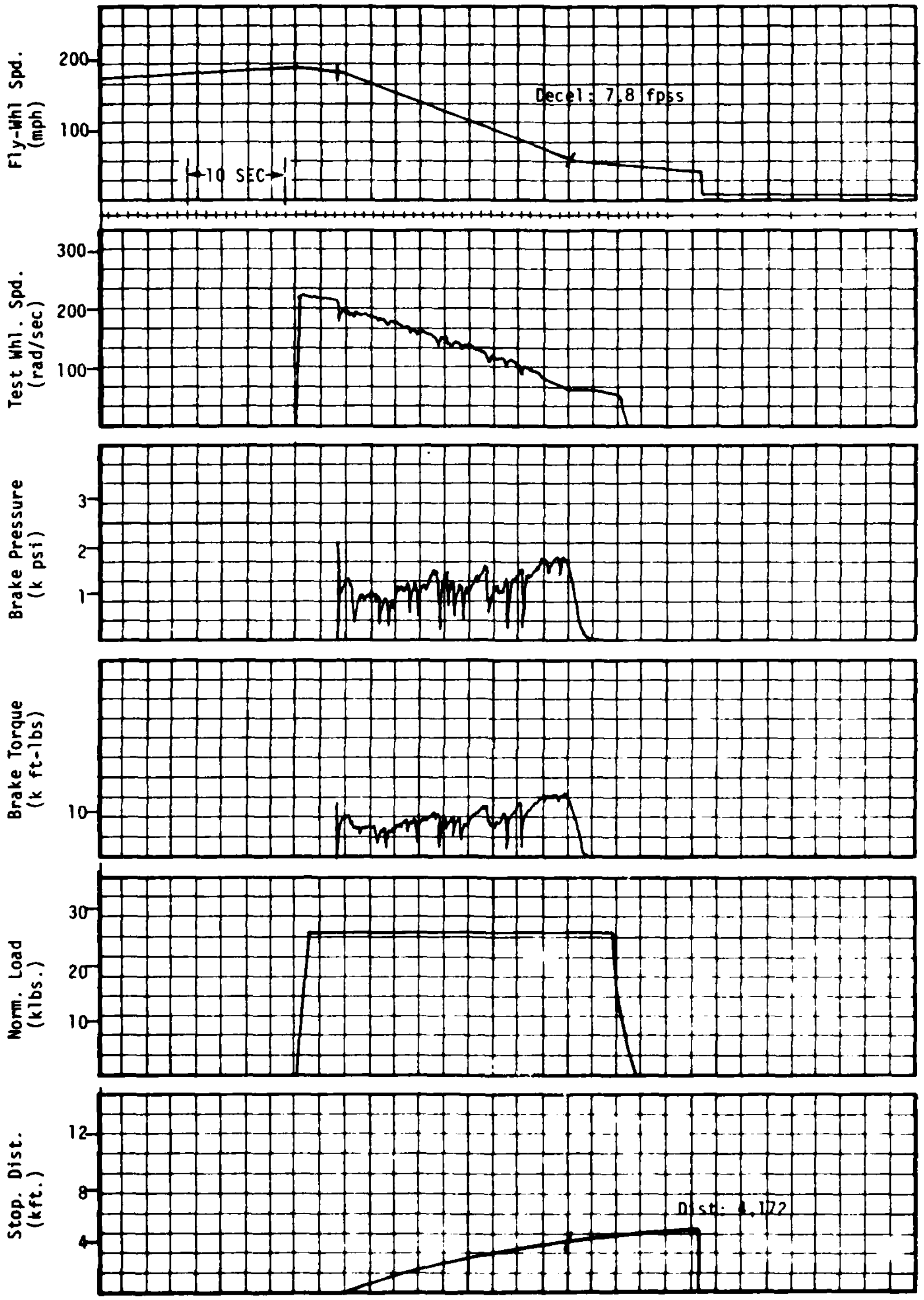


Figure C-13. S/N1174(20-N), Siped N/A, Cyc. 61, 0.5 gpm

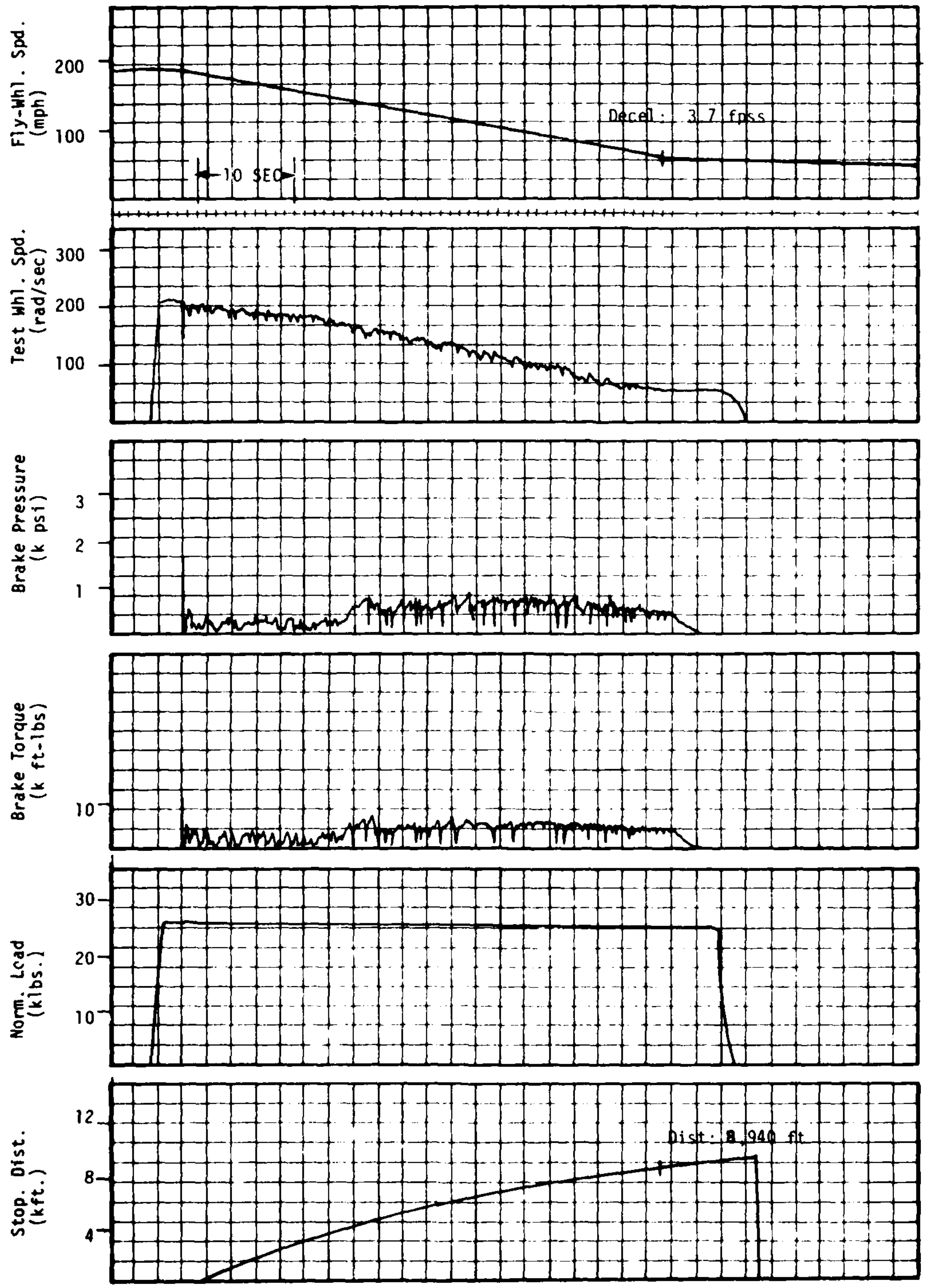


Figure C-14. S/N1174(20-N), Siped N/A, Cyc. 62, 1.0 gpm

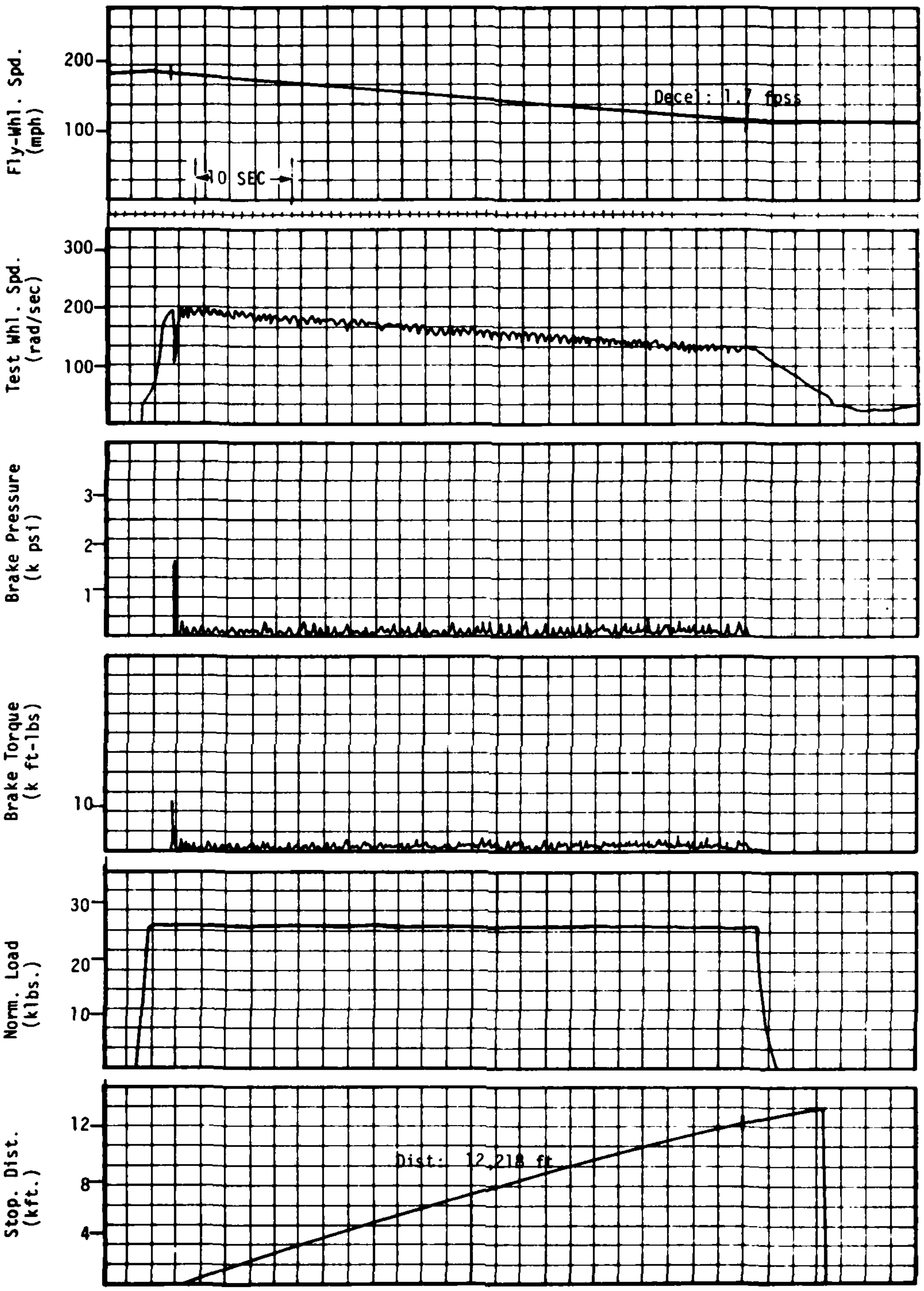


Figure C-15. S/N1174(20-N), Siped N/A, Cyc. 63, 2.0 gpm

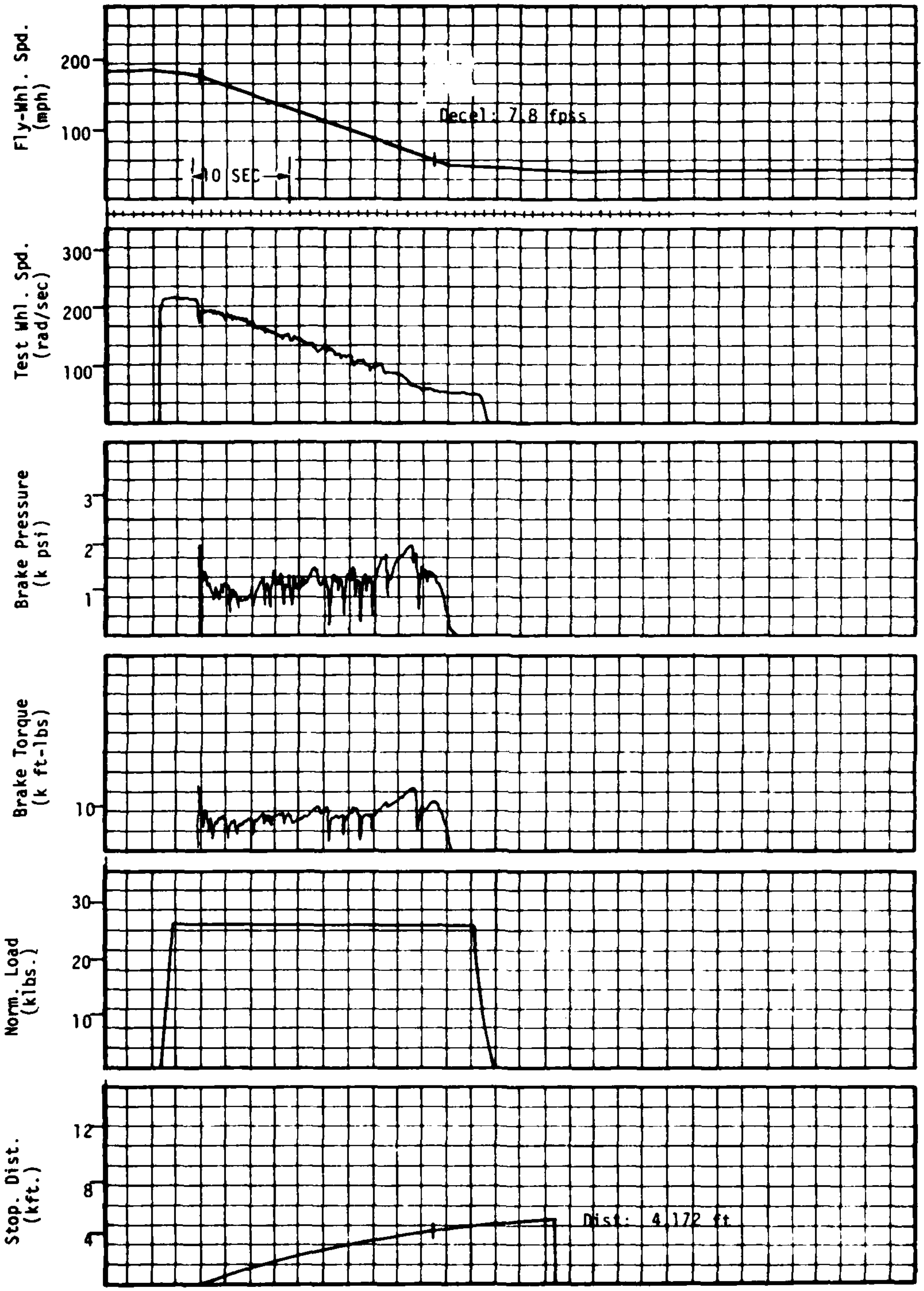


Figure C-16. S/N1174(20-N), Siped 3/16" X 8/32", Cyc. 64, 0.5 gpm

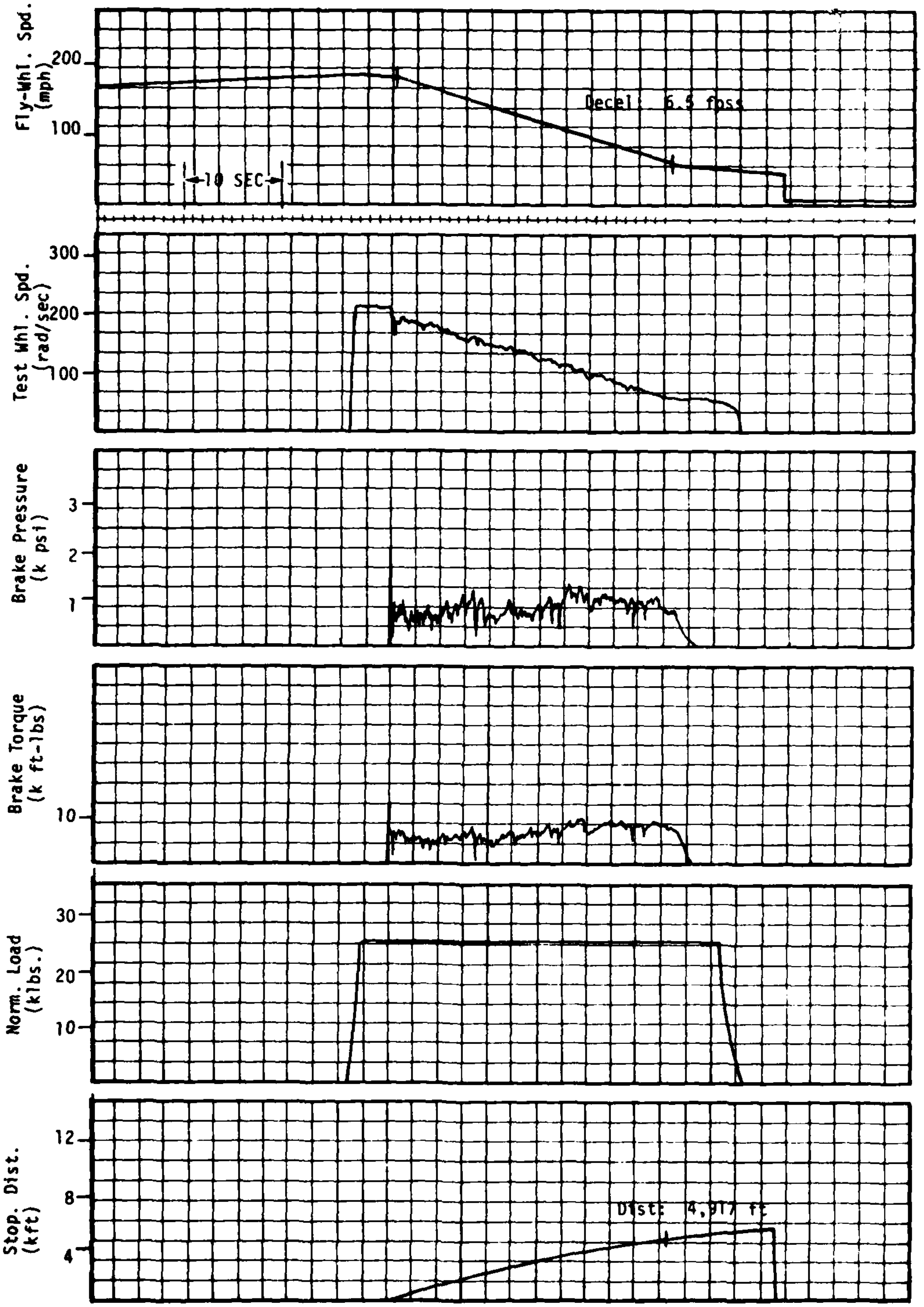


Figure C-17. S/N1174(20-N), Siped 3/16" X 8/32", Cyc. 65, 1.0 gpm

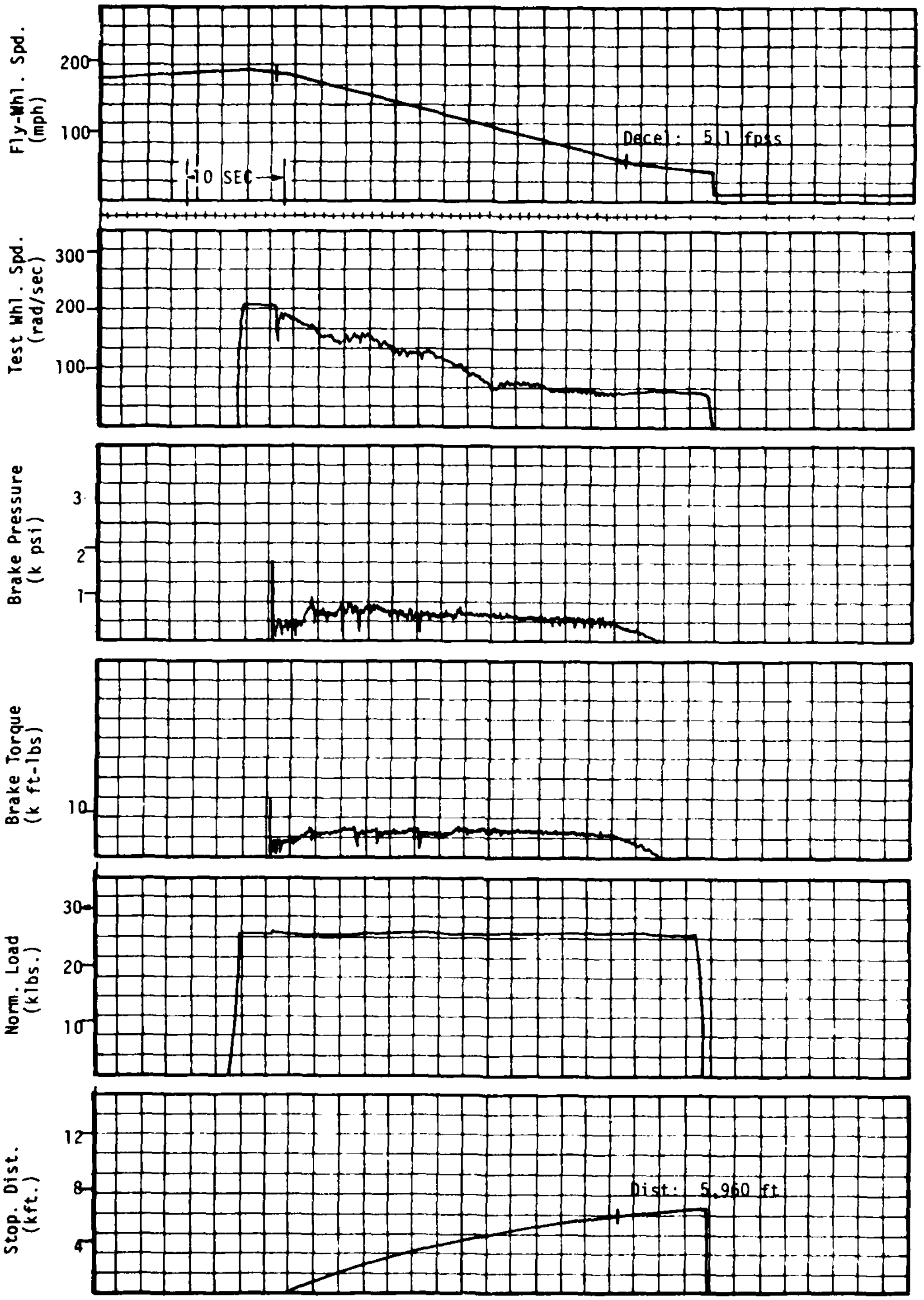


Figure C-18. S/N1174(20-N), Siped 3/16" X 8/32", Cyc. 66, 2.0 gpm

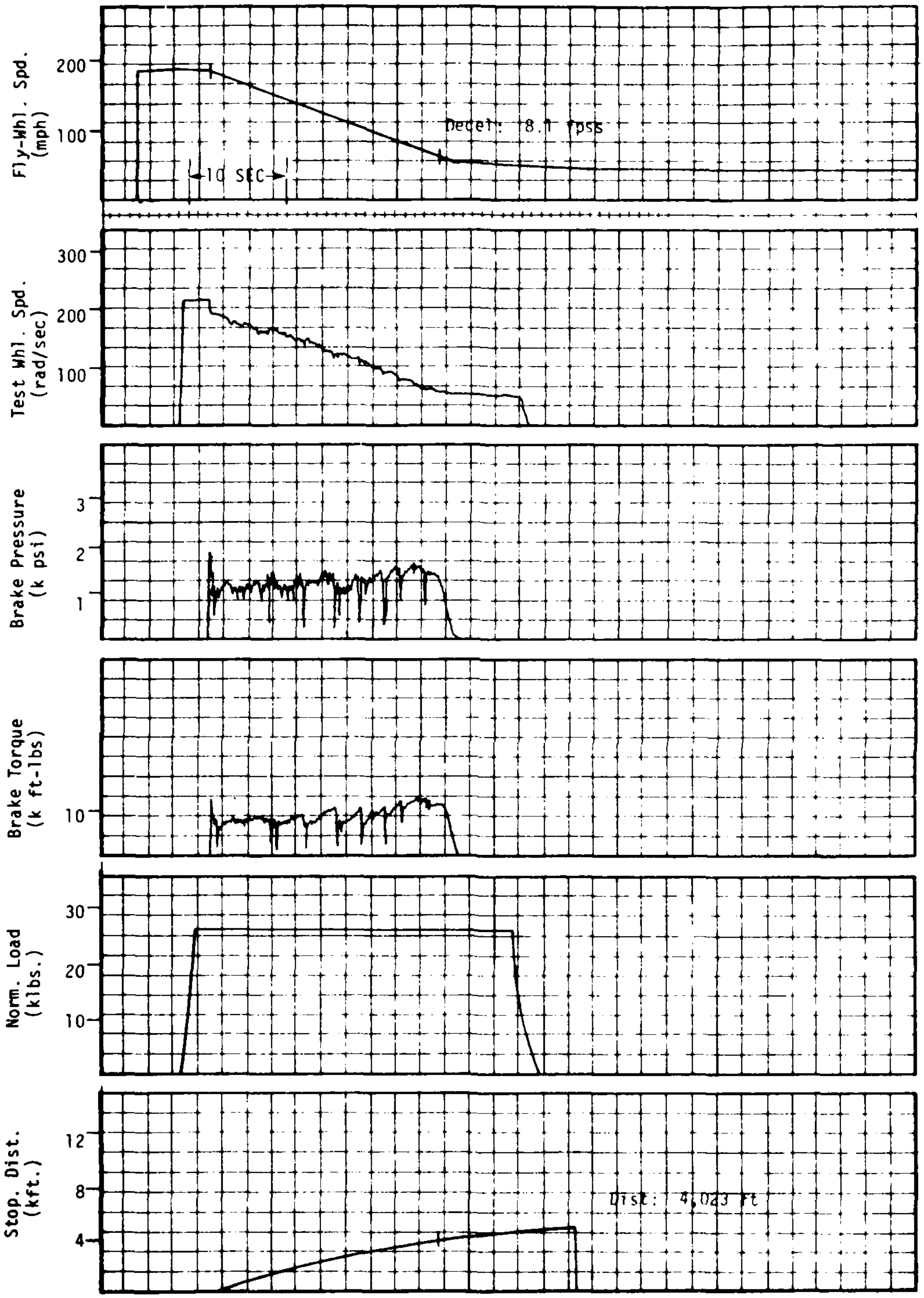


Figure C-19. S/N1185(21-N), Siped N/A, Cyc. 67, 0.5 gpm

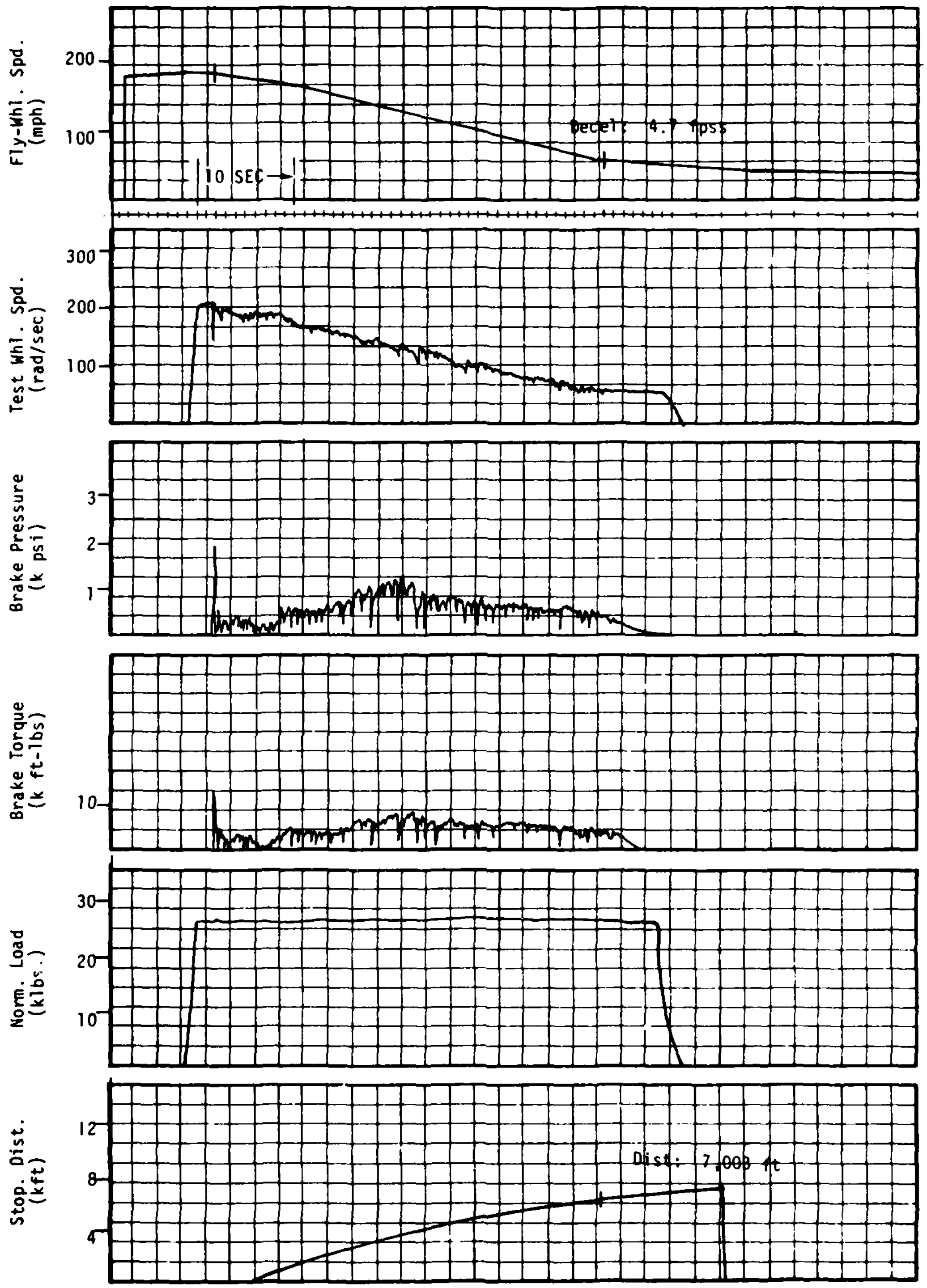


Figure C-20. S/N1185(21-N), Siped N/A, Cyc. 68, 1.0 gpm

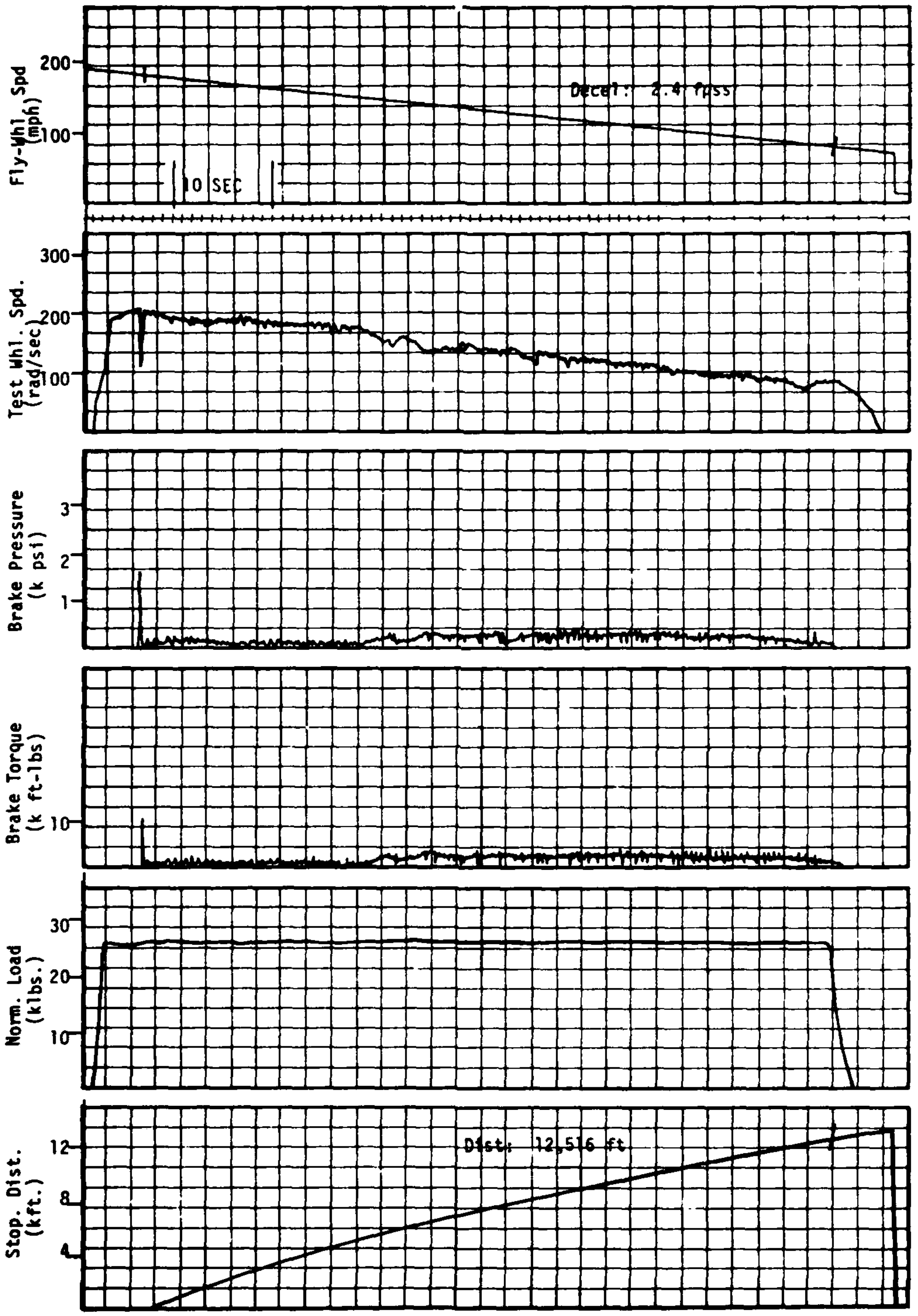


Figure C-21. S/N1185(21-N), Siped N/A, Cyc. 69, 2.0 gpm

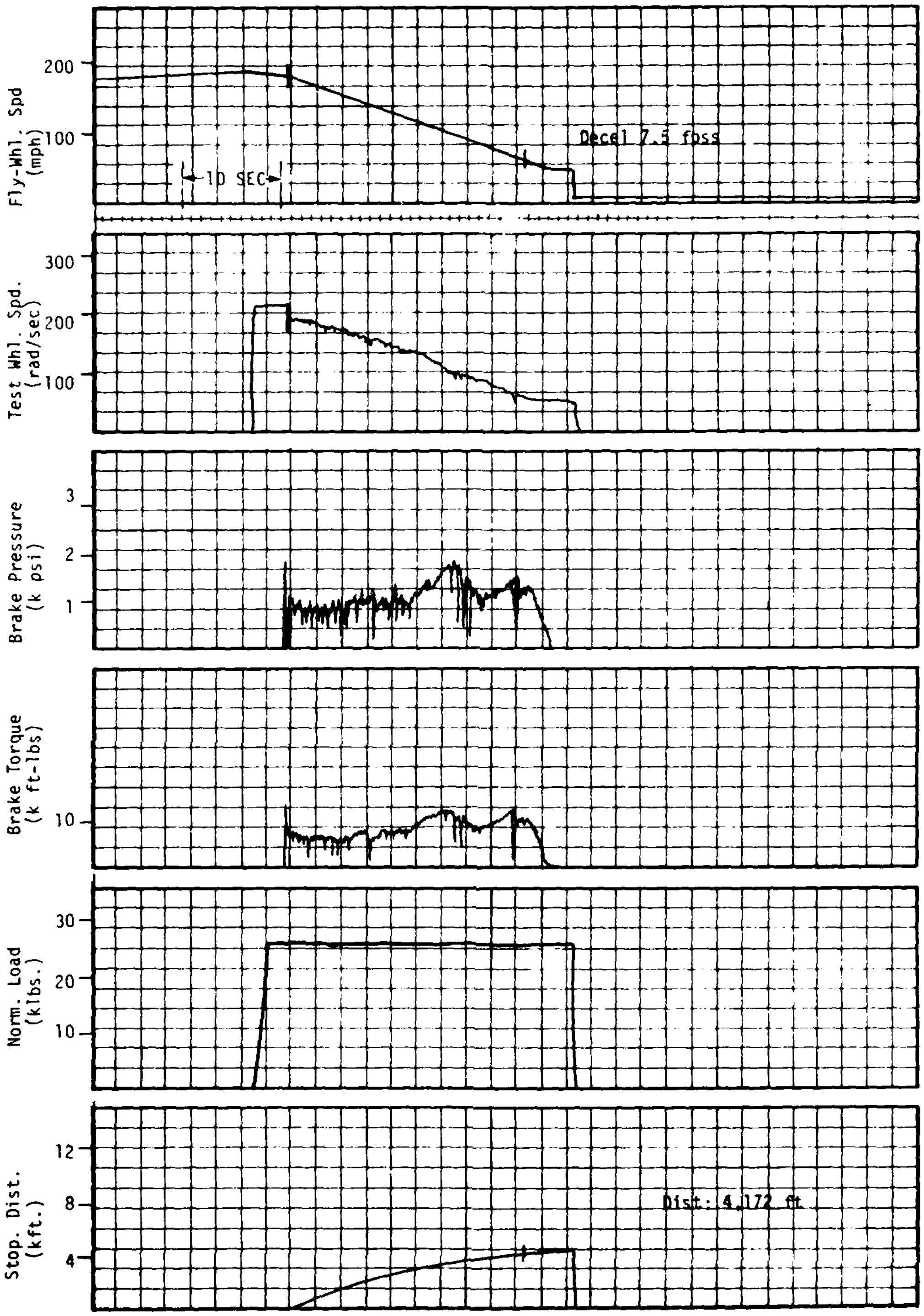


Figure C-22. S/N1293(22-N), Siped N/A, Cyc. 70, 0.5 gpm

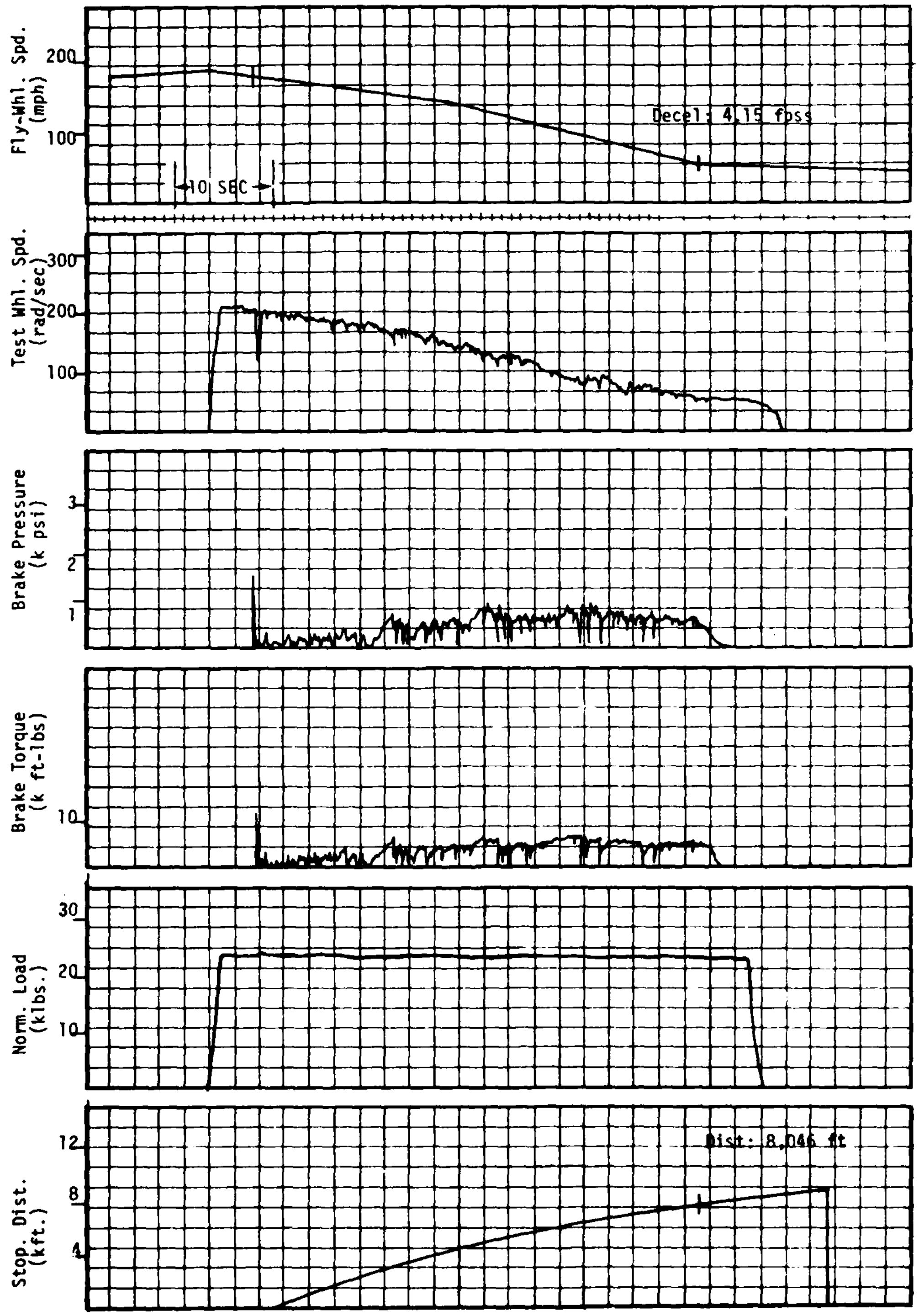


Figure C-23. S/N1293(22-N), Siped N/A, Cyc. 71, 1.0 gpm

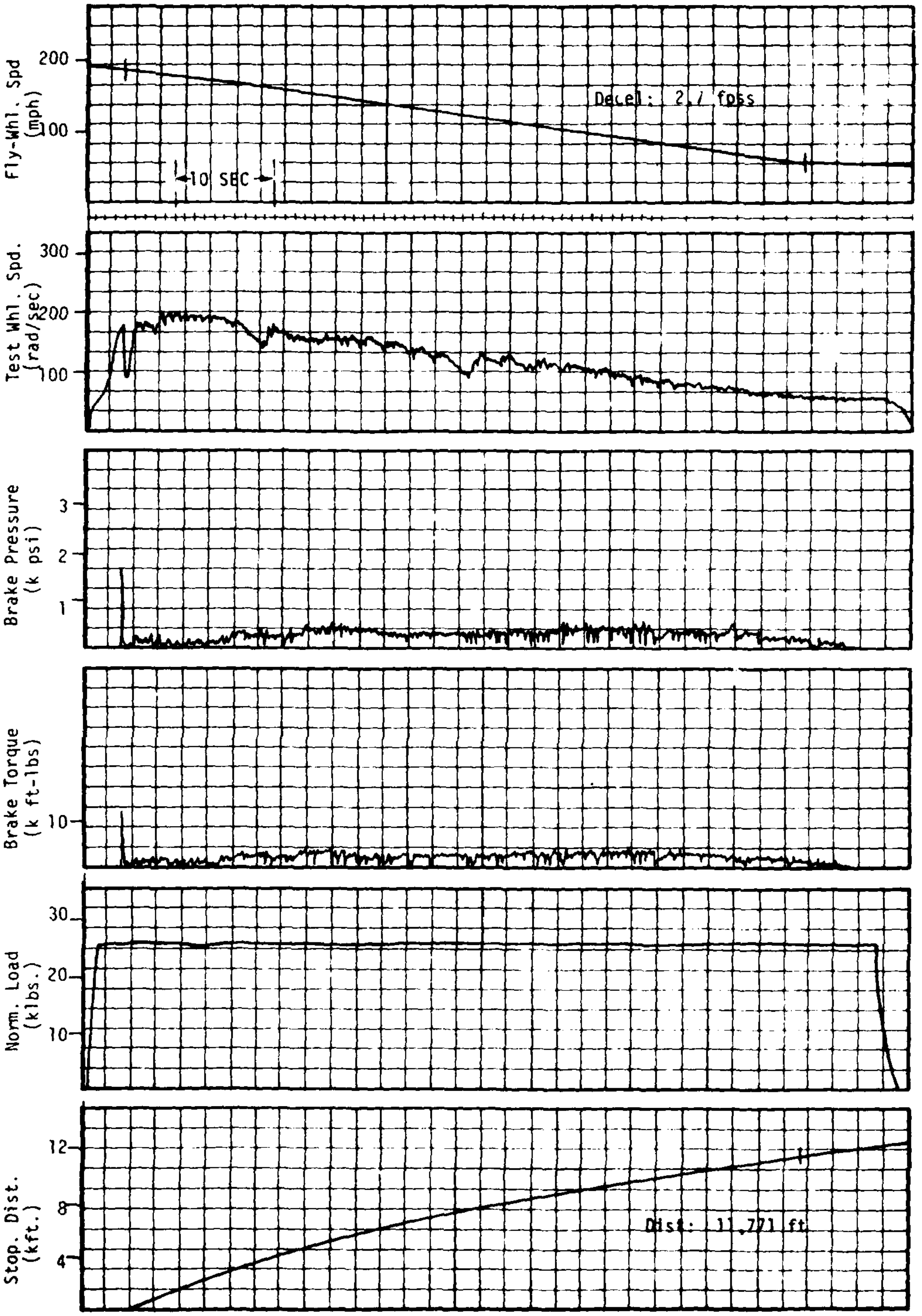


Figure C-24. S/N1293(22-N), Siped N/A, Cyc. 72, 2.0 gpm

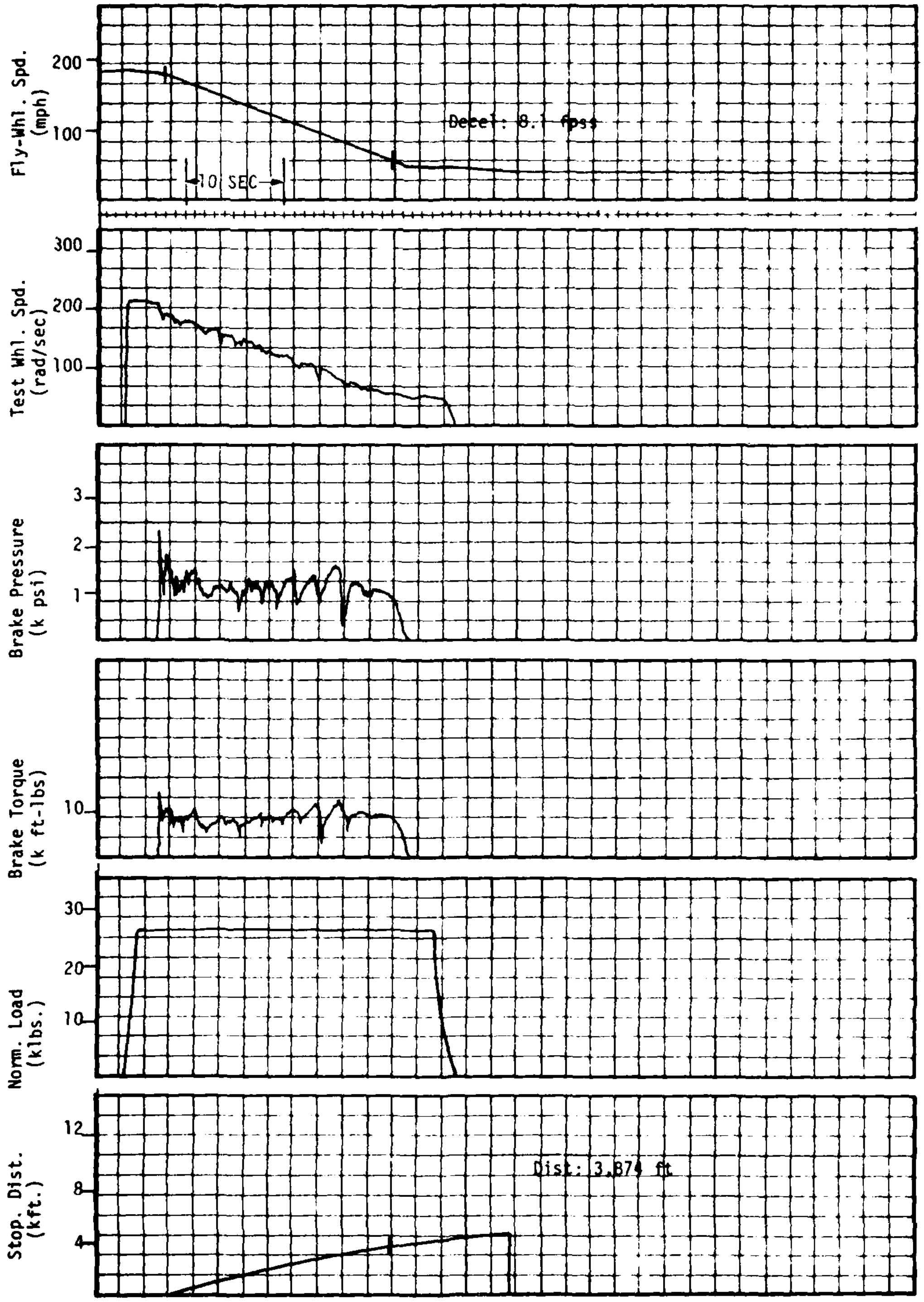


Figure C-25. S/N118S(21-N), Siped 3/16" X 5/32", Cyc. 73, 0.5 gpm

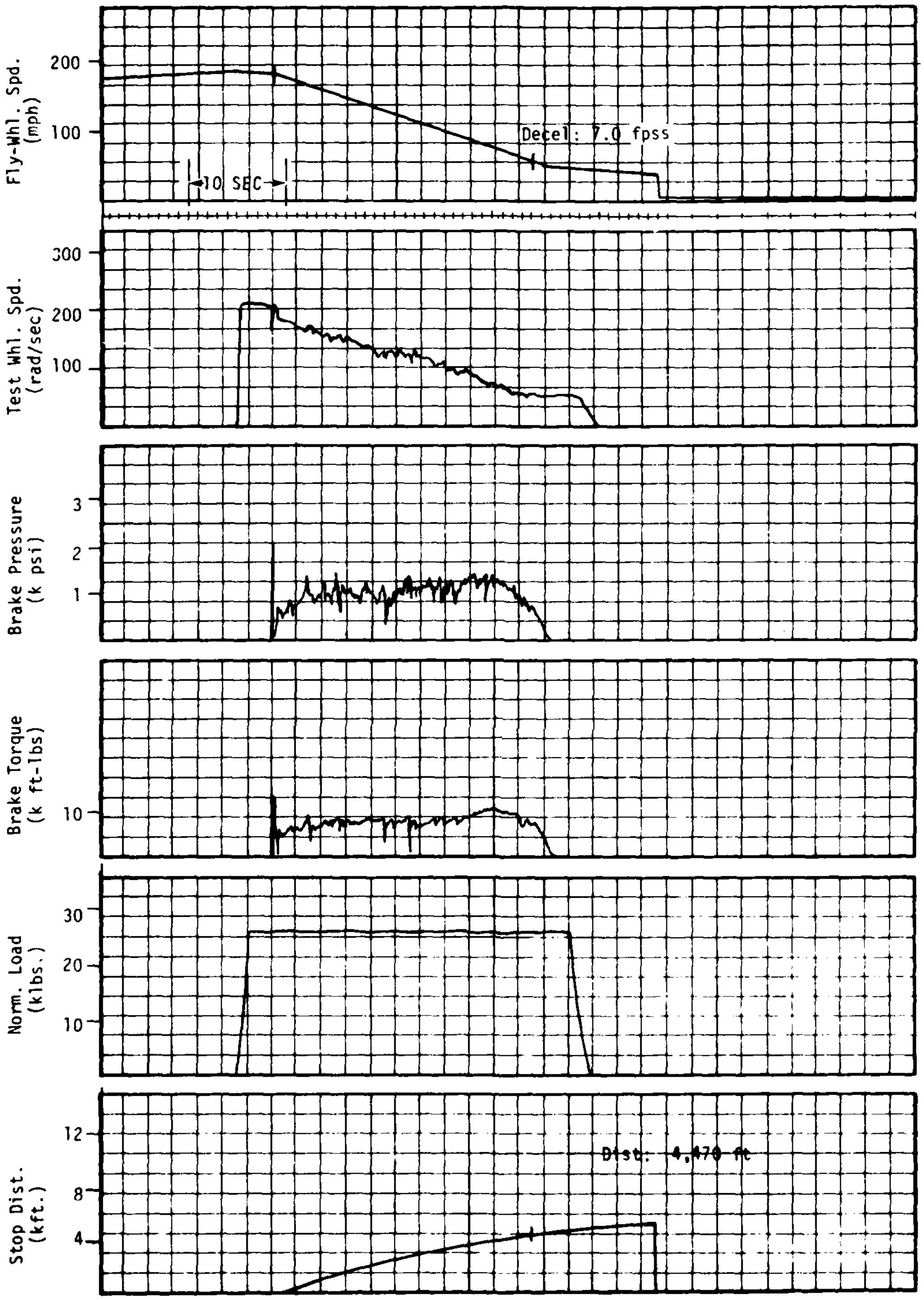


Figure C-26. S/N1185(21-N), Siped 3/16" X 5/32", Cyc. 74, 1.0 gpm

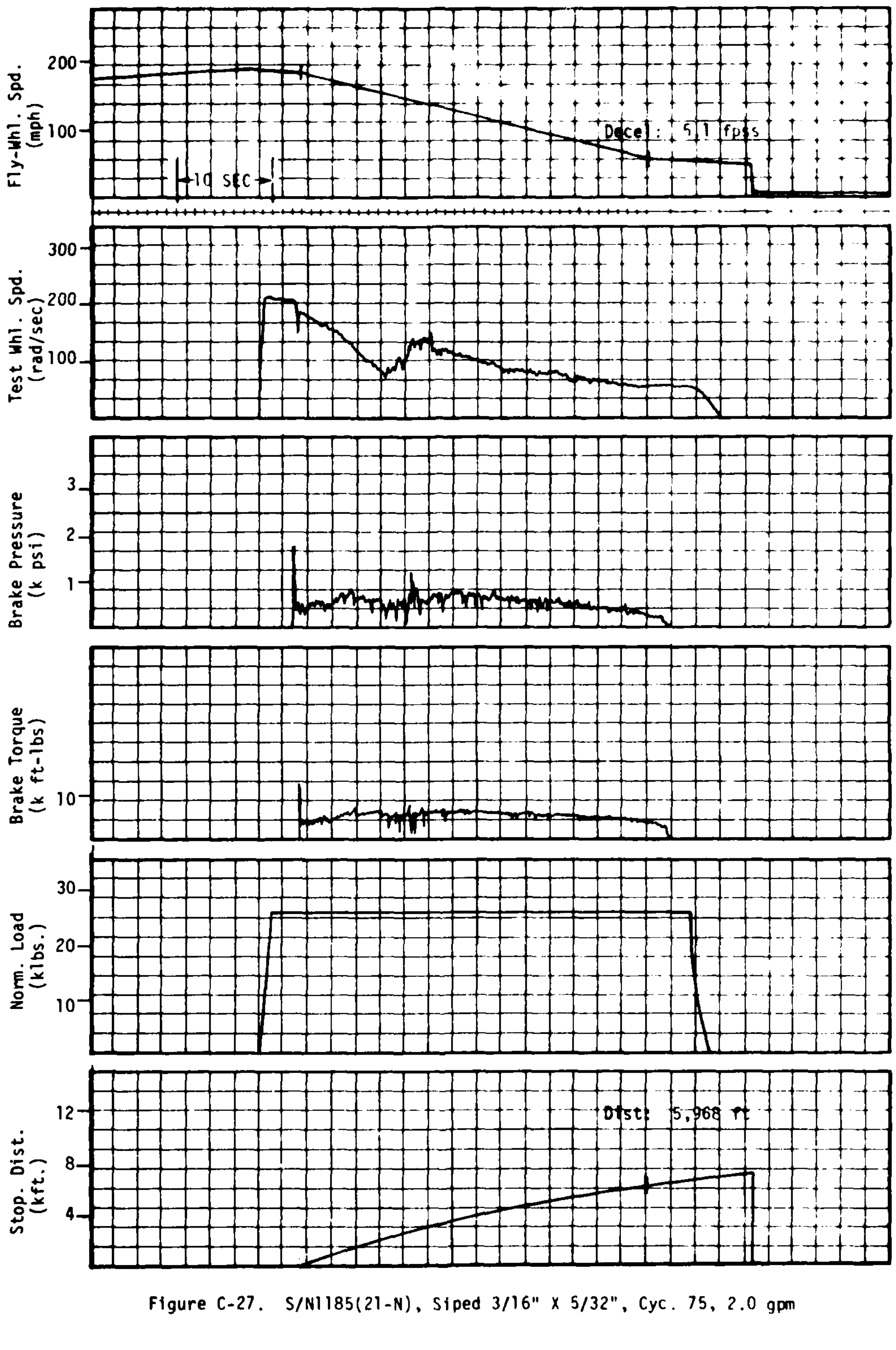


Figure C-27. S/N1185(21-N), Siped 3/16" X 5/32", Cyc. 75, 2.0 gpm

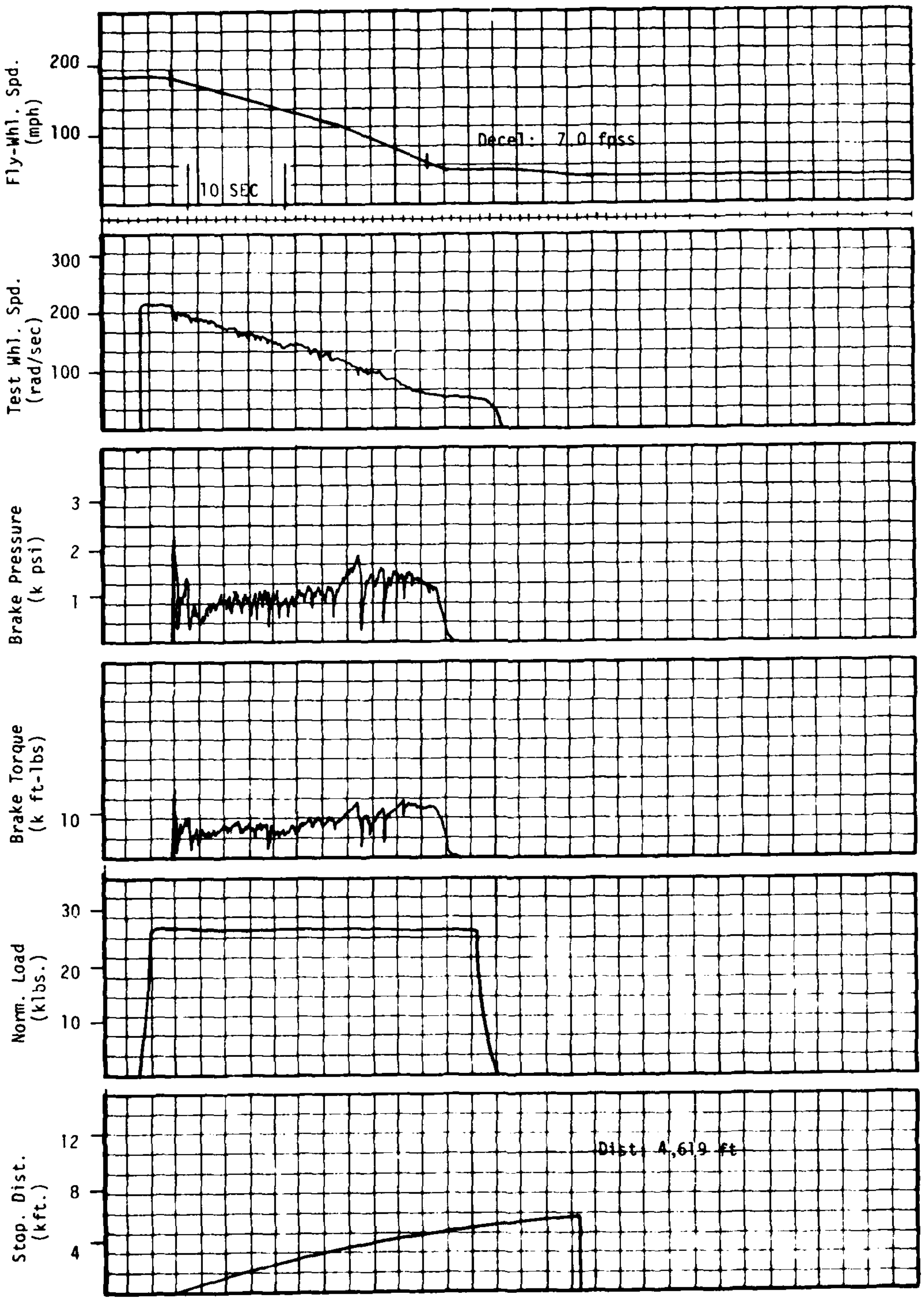


Figure C-28. S/N1293(22-N), Siped 3/16" X 8/32", Cyc. 76, 0.5 gpm

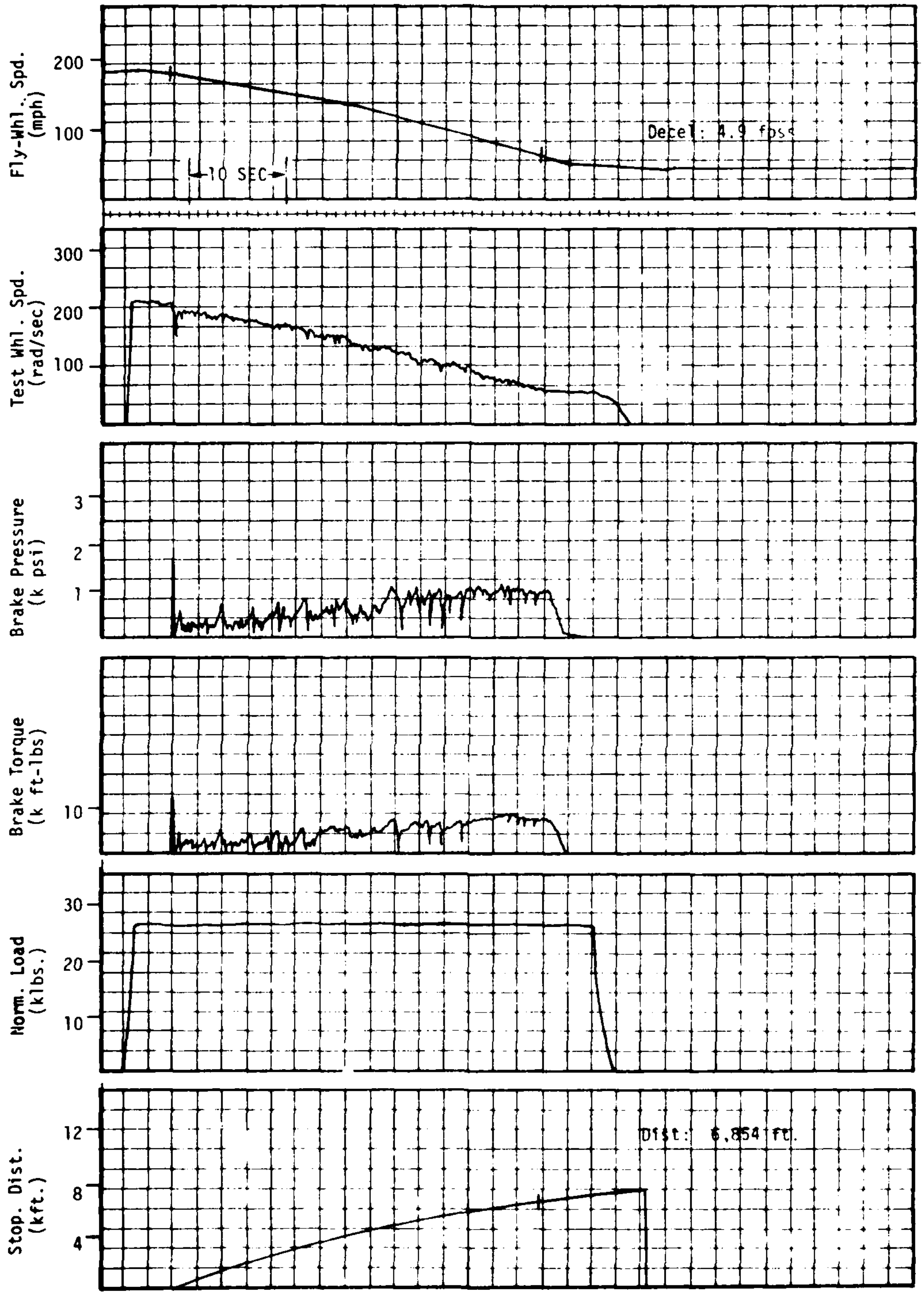


Figure C-29. S/N1293(22-N), Siped 3/16" X 8/32", Cyc. 77, 1.0 gpm

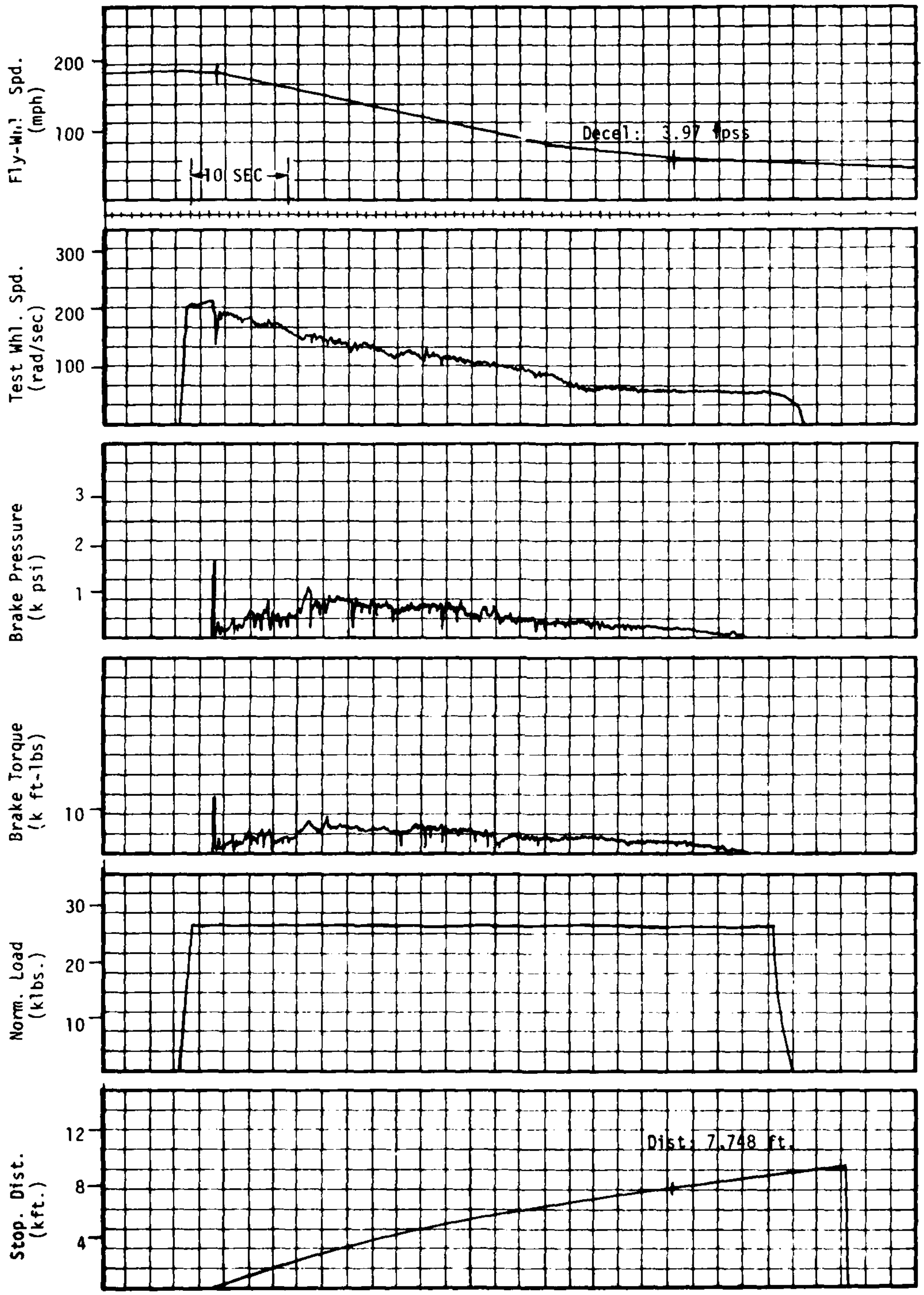


Figure C-30. S/N1293(22-N), Siped 3/16" X 8/32", Cyc. 78, 2.0 gpm

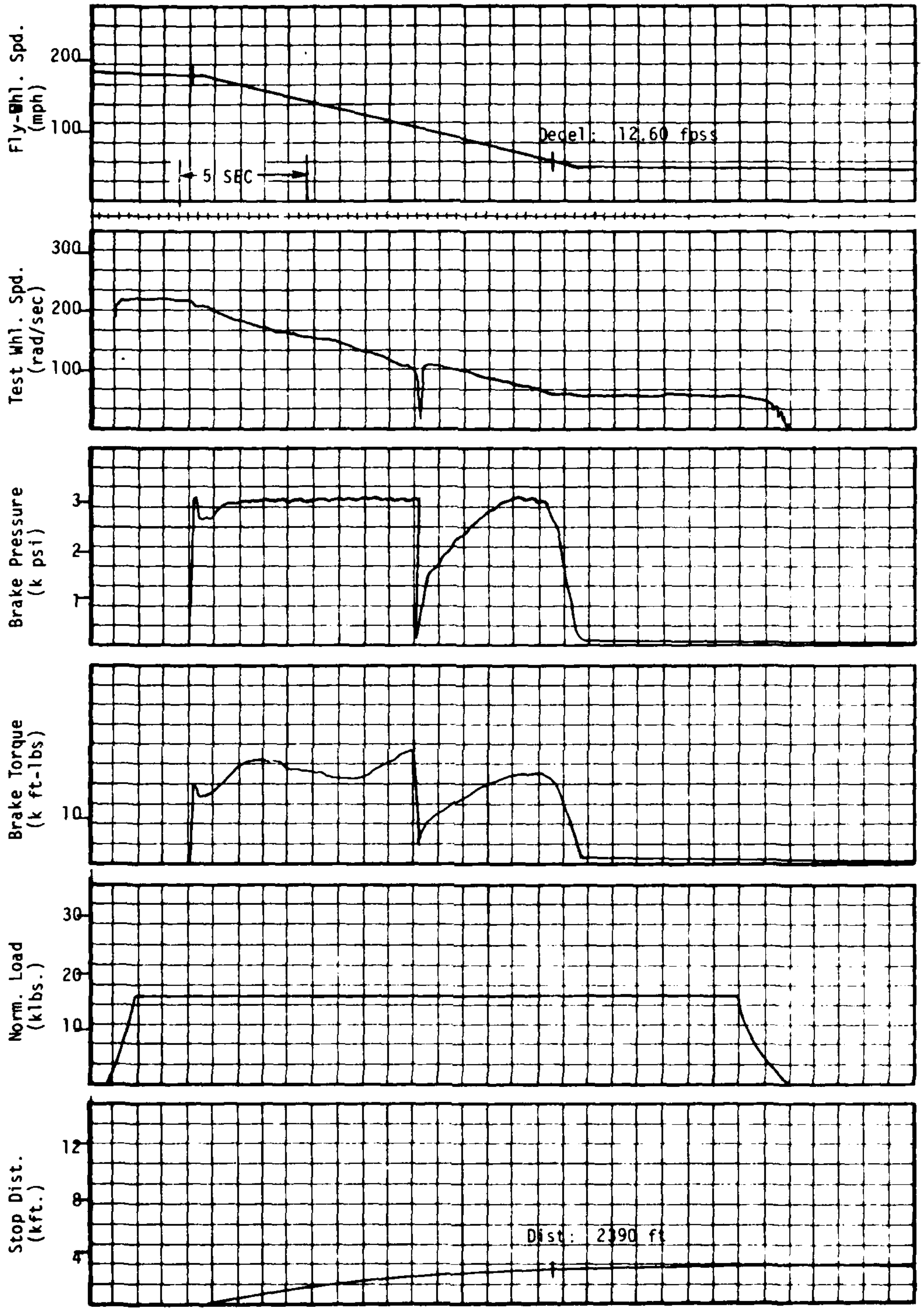


Figure C-31. S/N1293(22-N), Siped 3/16" X 8/32", Cyc. 90, DRY gpm

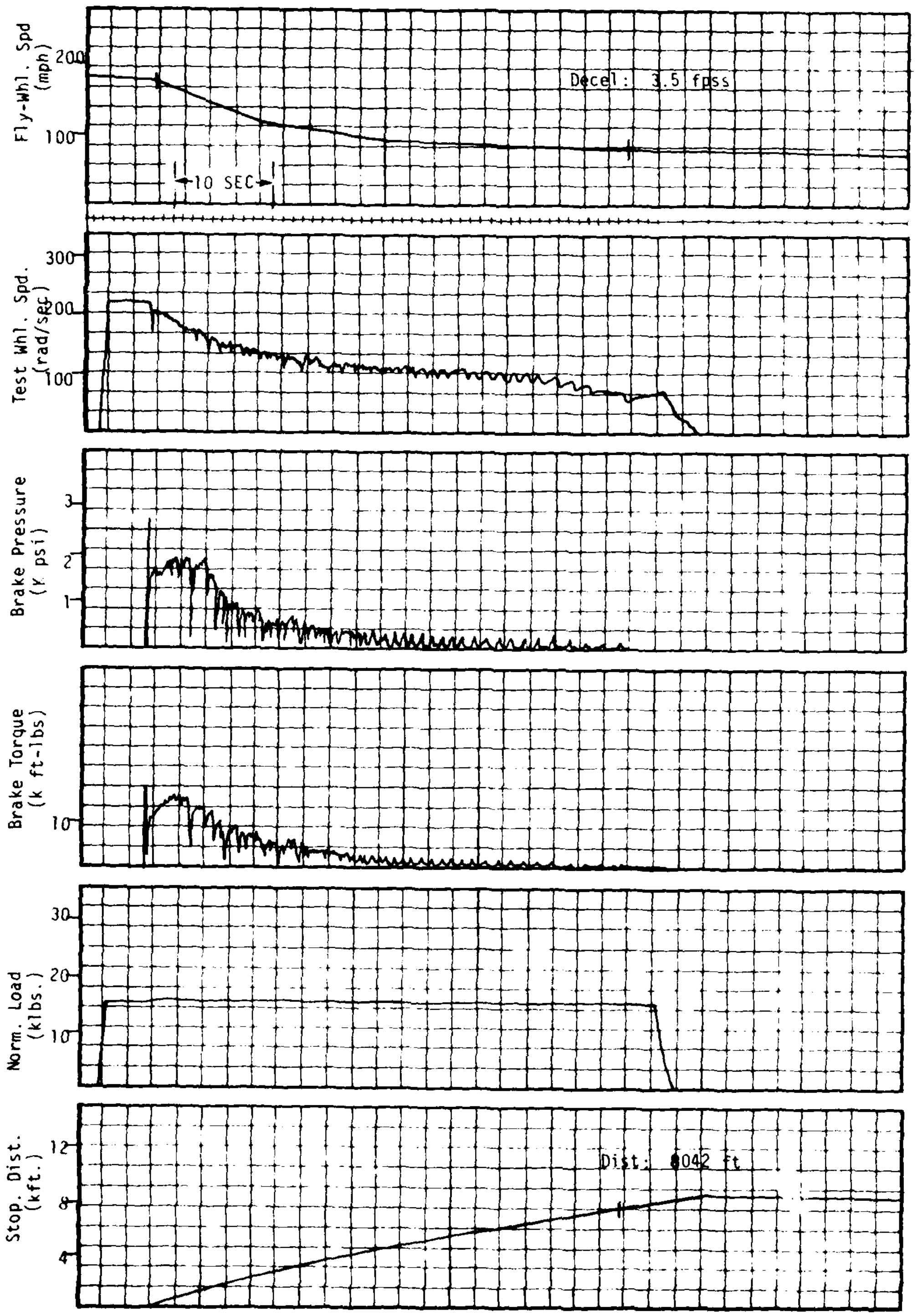


Figure C-32. S/N6A0013(#1-R-2), Siped N/A, Cyc. 96, 0.5 gpm

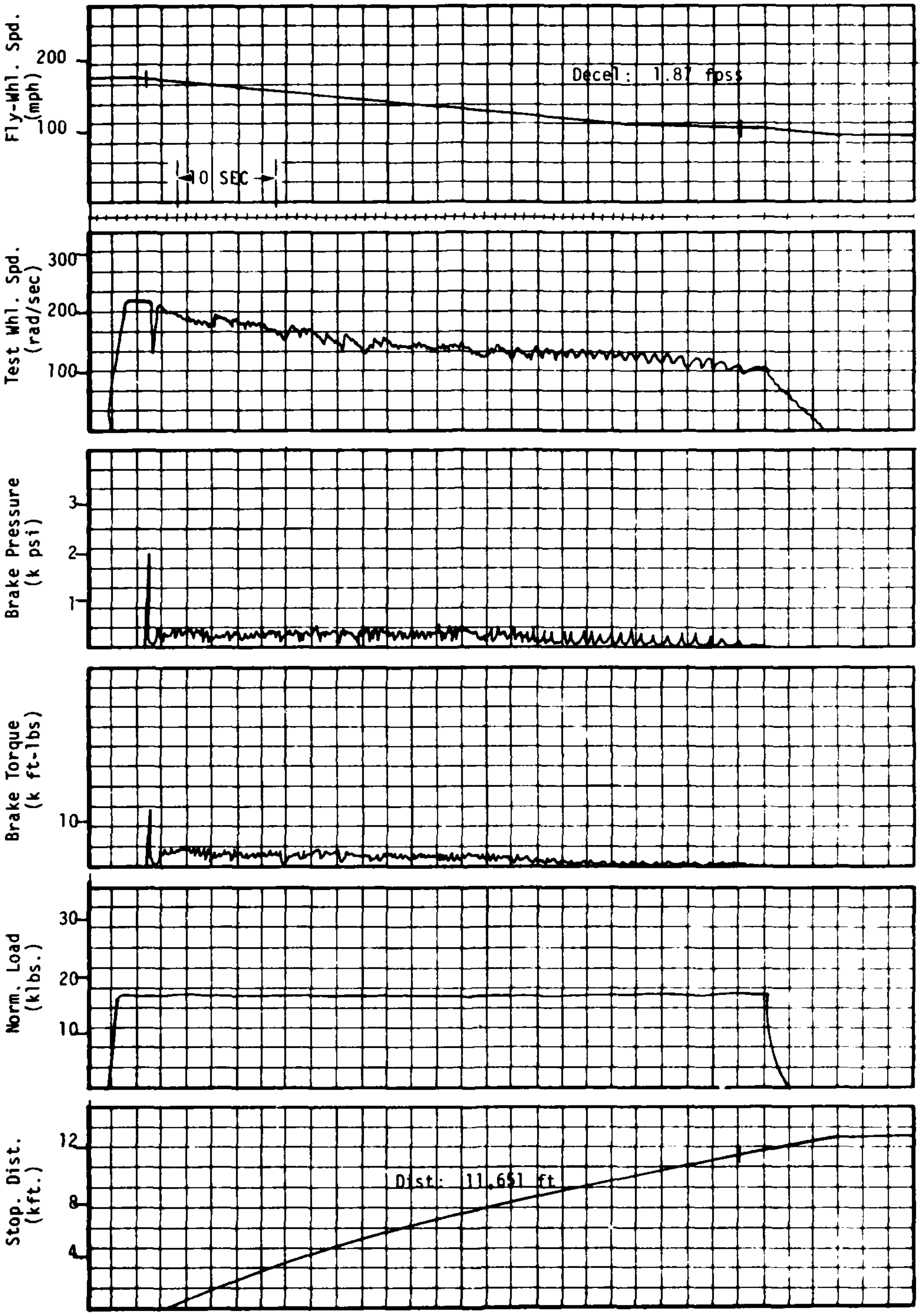


Figure C-33. S/N6A0013(#1-R-2), Siped N/A, Cyc. 97, 1.0 gpm

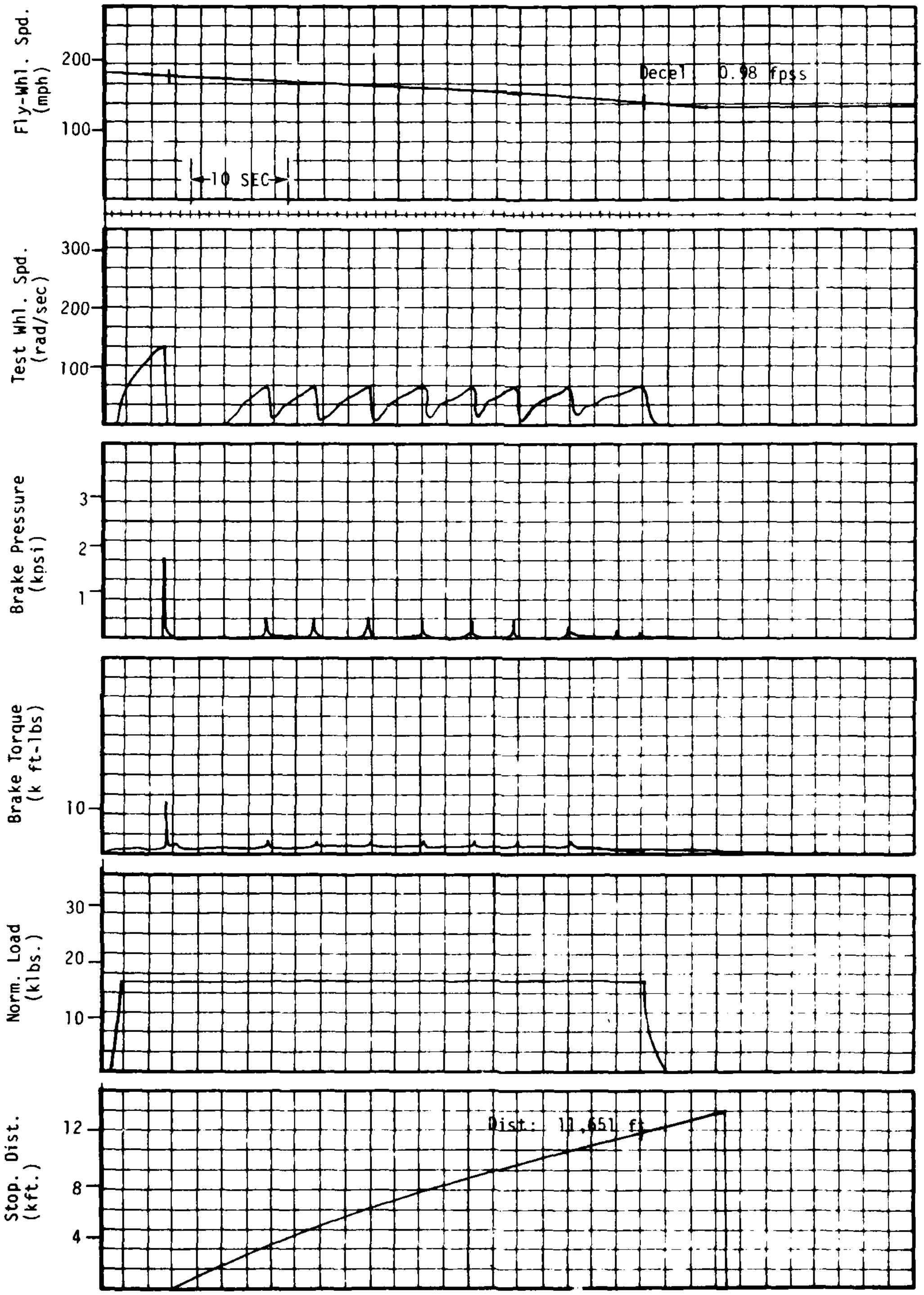


Figure C-34. S/N6A0013(#1-R-2), Siped N/A, Cyc. 98, 2.0 gpm

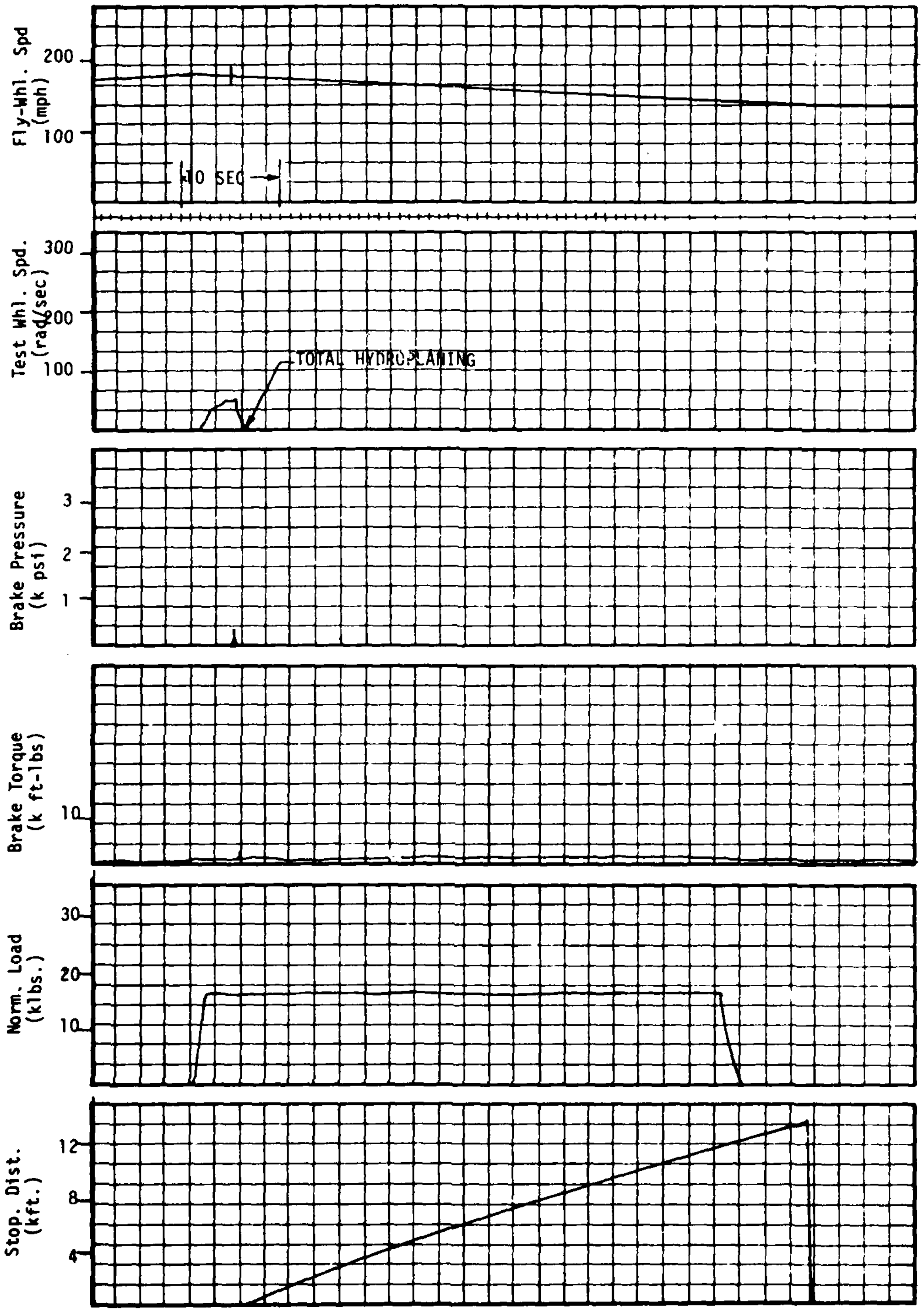


Figure C-35. S/N6A0013(#1-R-2), Siped N/A, Cyc. 99, 3.0 gpm

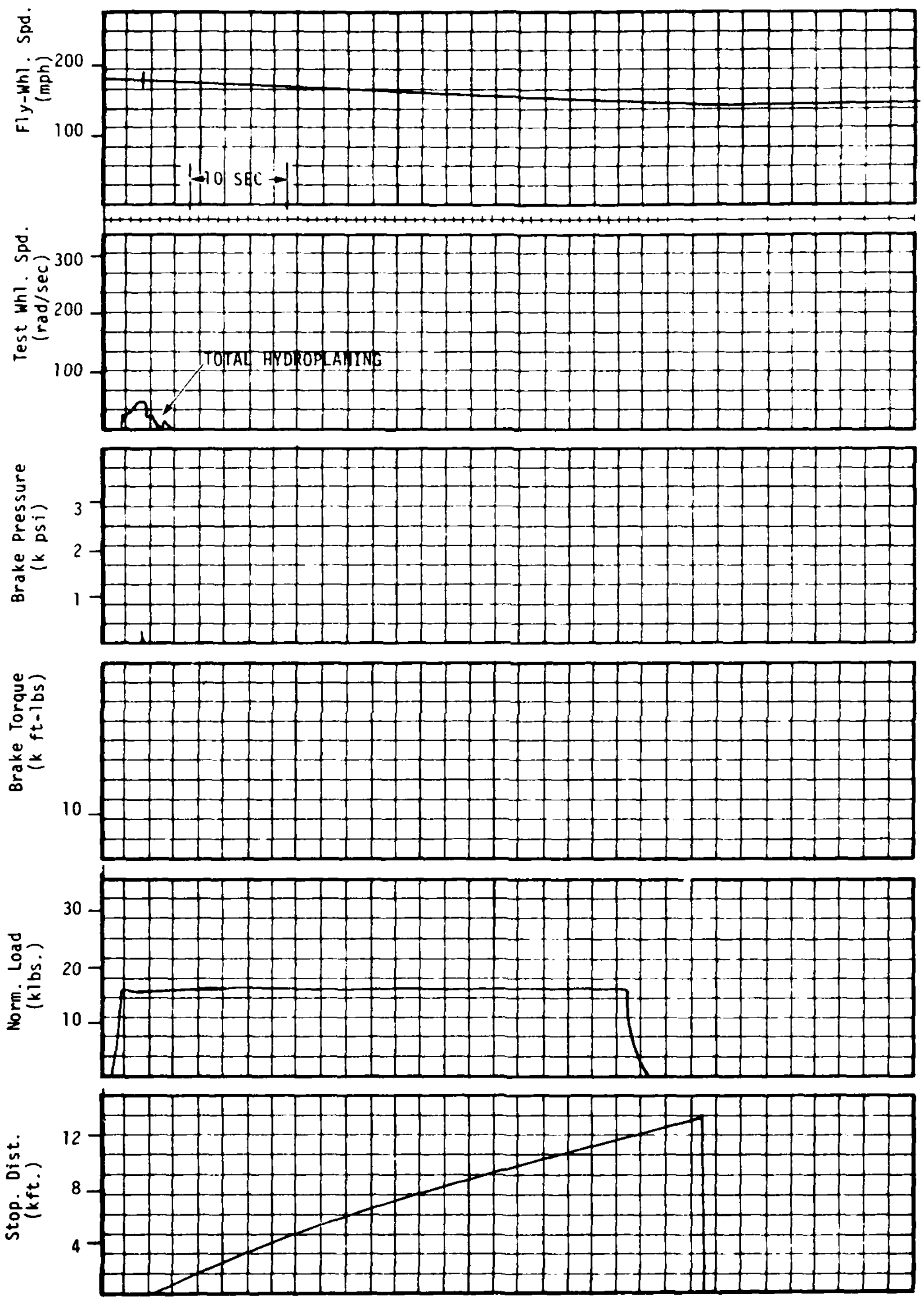


Figure C-36. S/N6A0013(#1-R-2), Siped N/A, Cyc. 100, 3.0 gpm

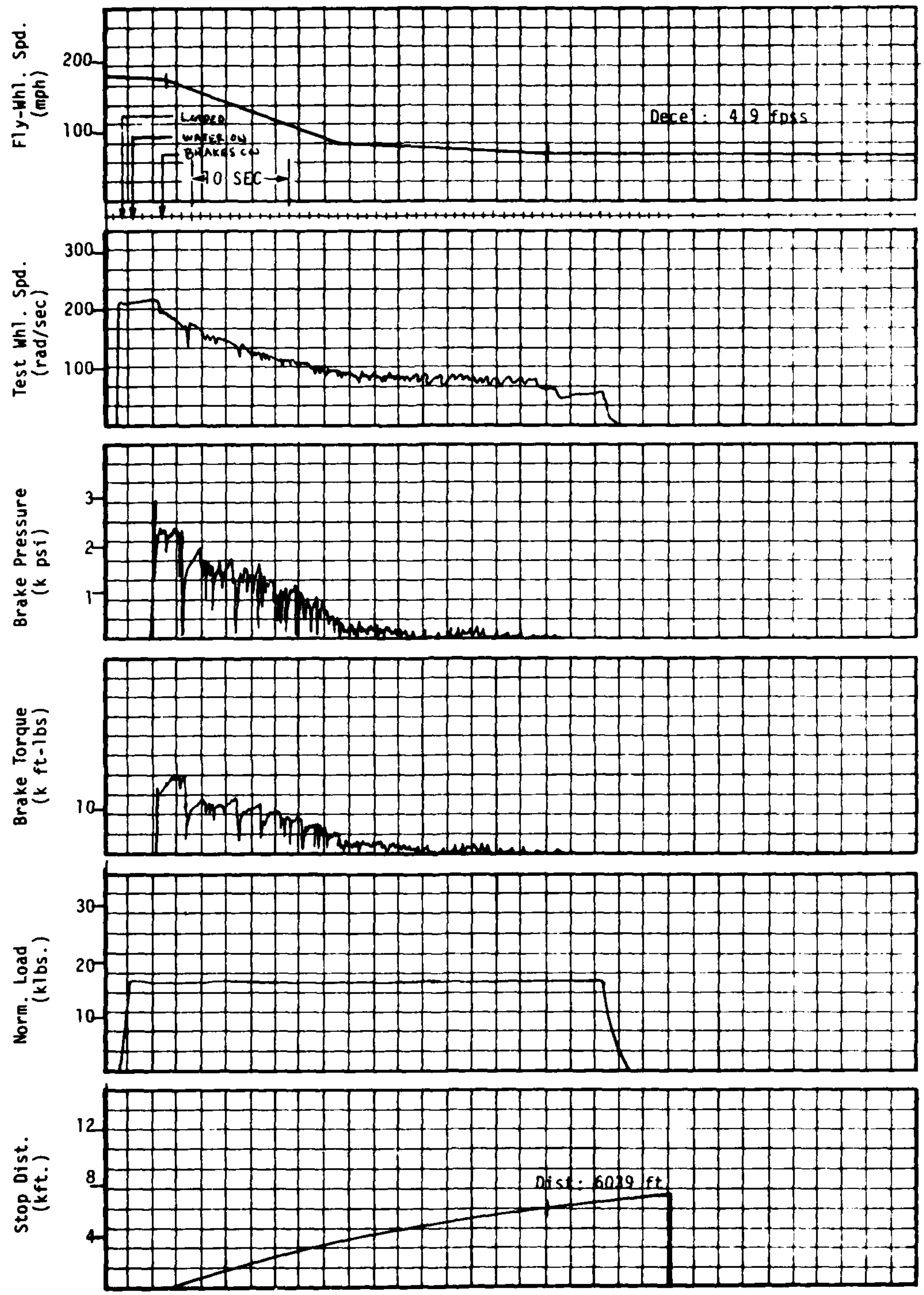


Figure C-37. S/N6A0013(#1-R-2), Siped N/A, Cyc. 101, 0.5 gpm

Water on After Landing

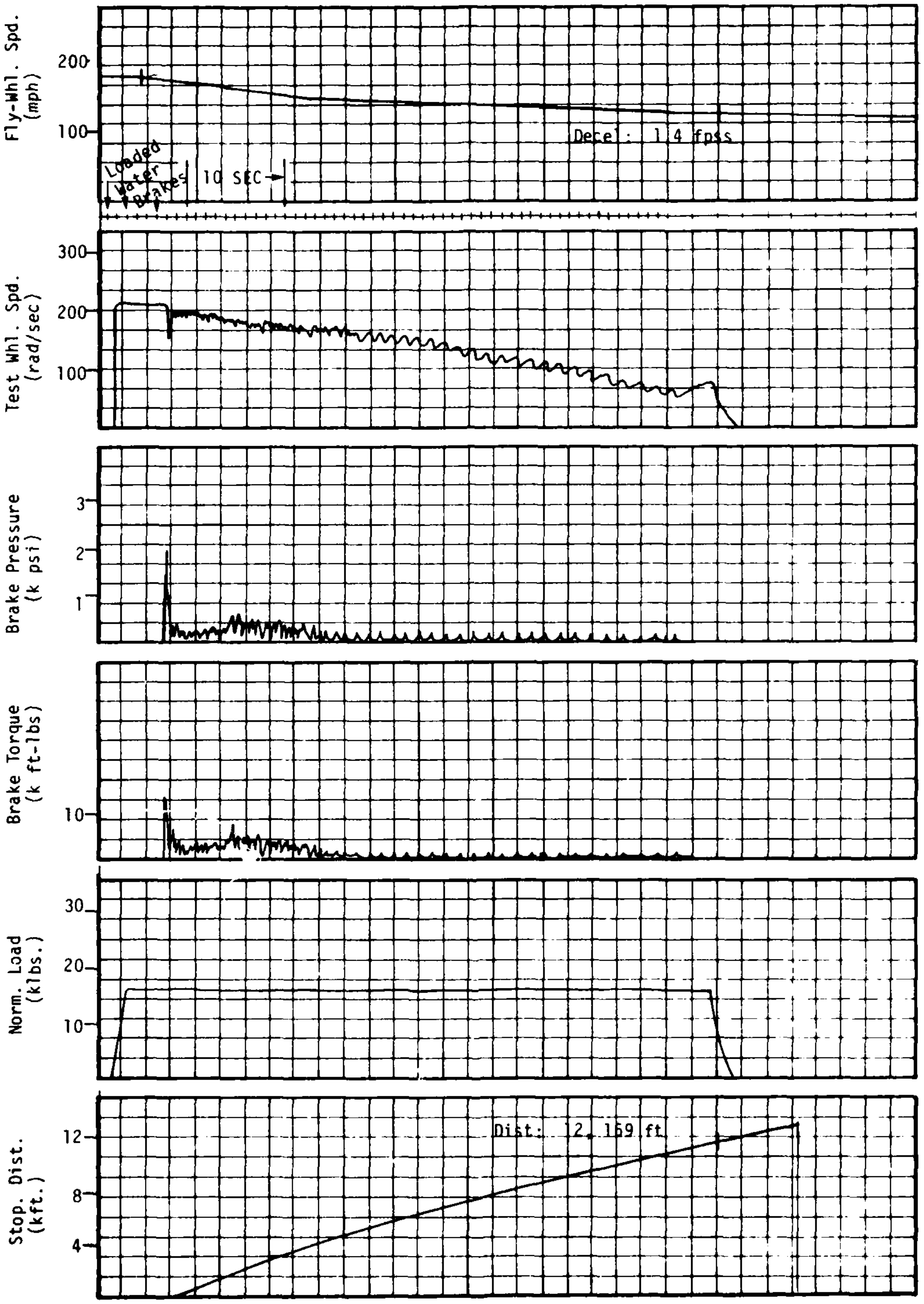


Figure C-38. S/N6A0013(#1-R-2), Siped N/A, Cyc. 102, 1.0 gpm
Water on After Landing

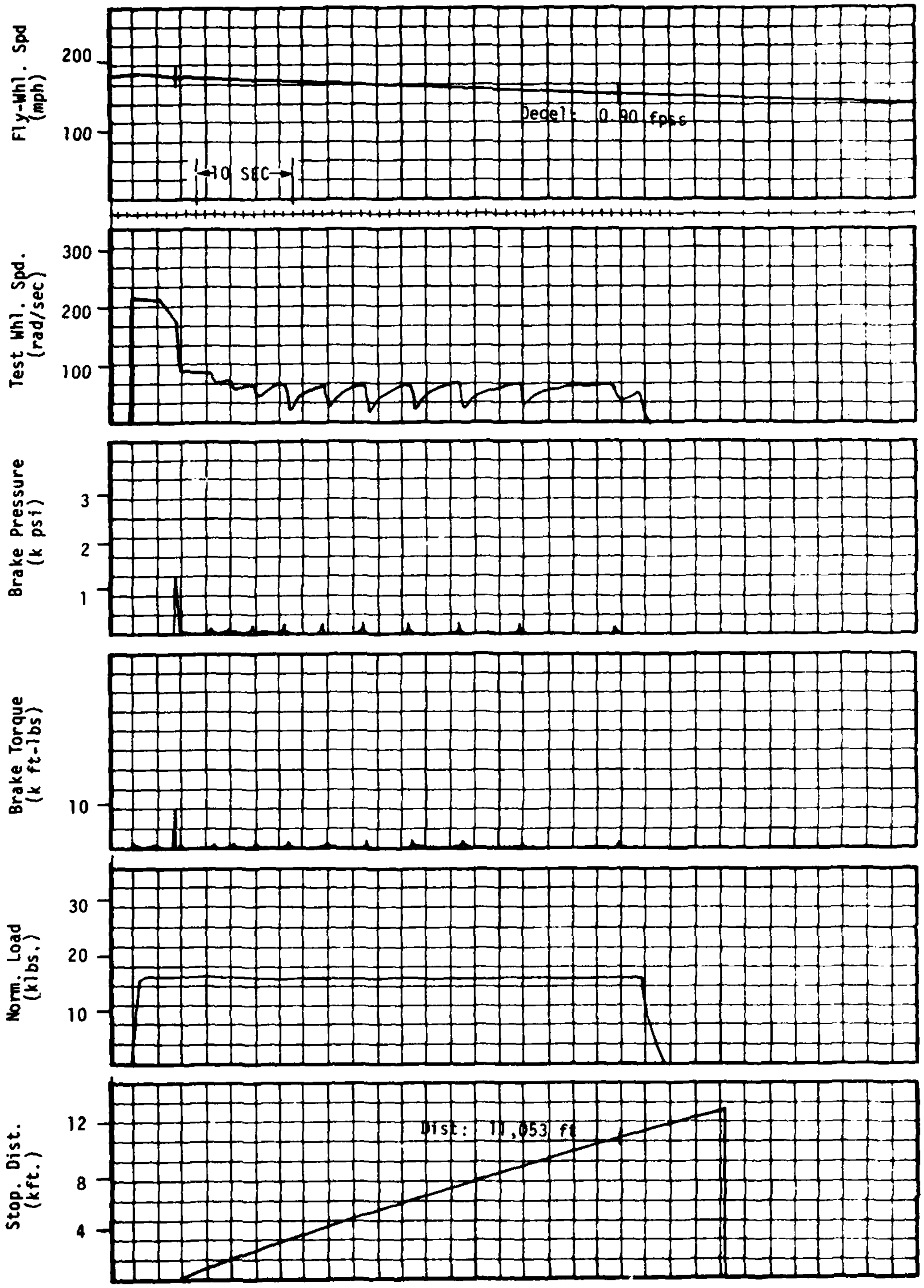


Figure C-39. S/N6A0013(#1-R-2), Siped N/A, Cyc. 103, 2.0 gpm
Water on After Landing

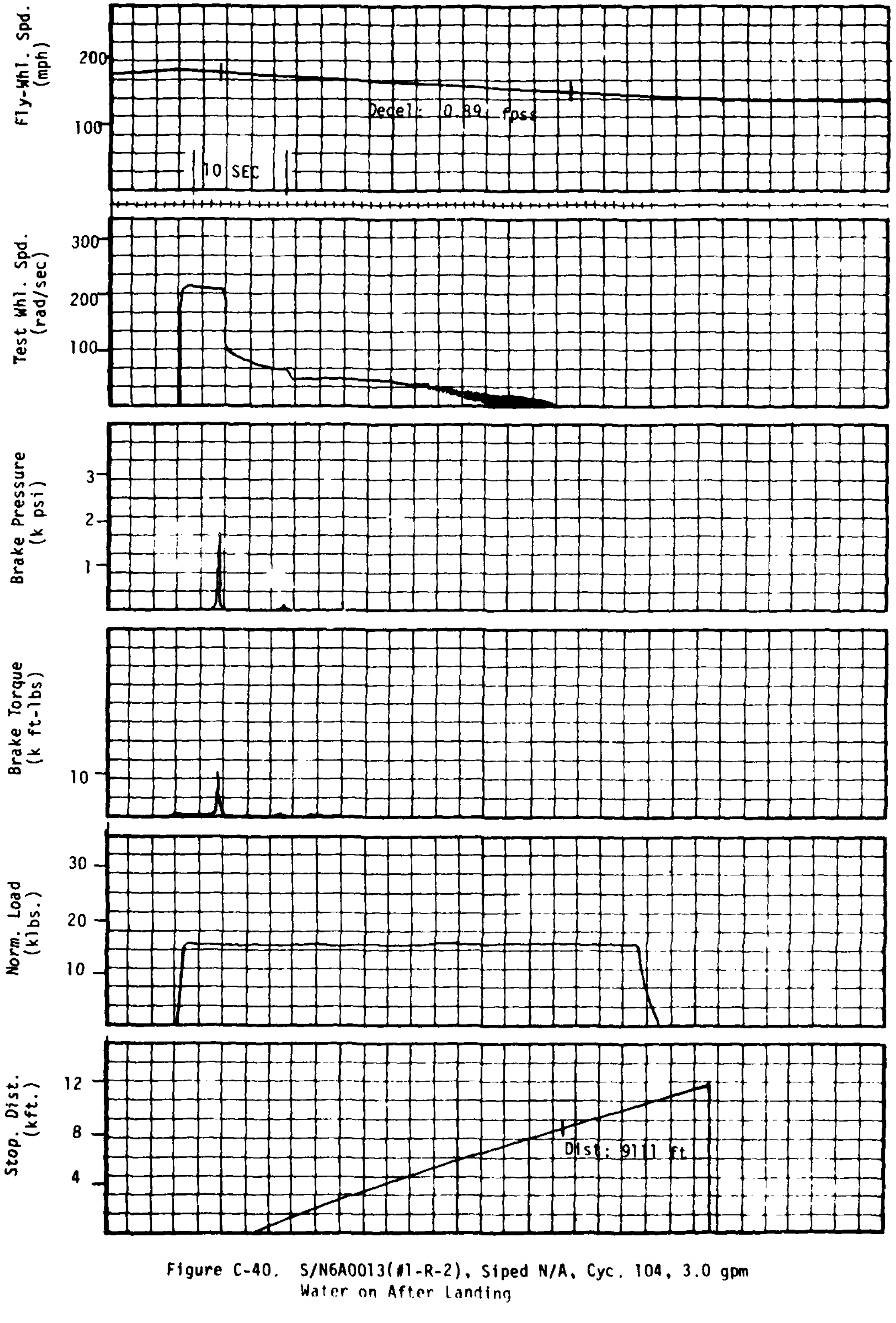


Figure C-40. S/N6A0013(#1-R-2), Siped N/A, Cyc. 104, 3.0 gpm
Water on After Landing

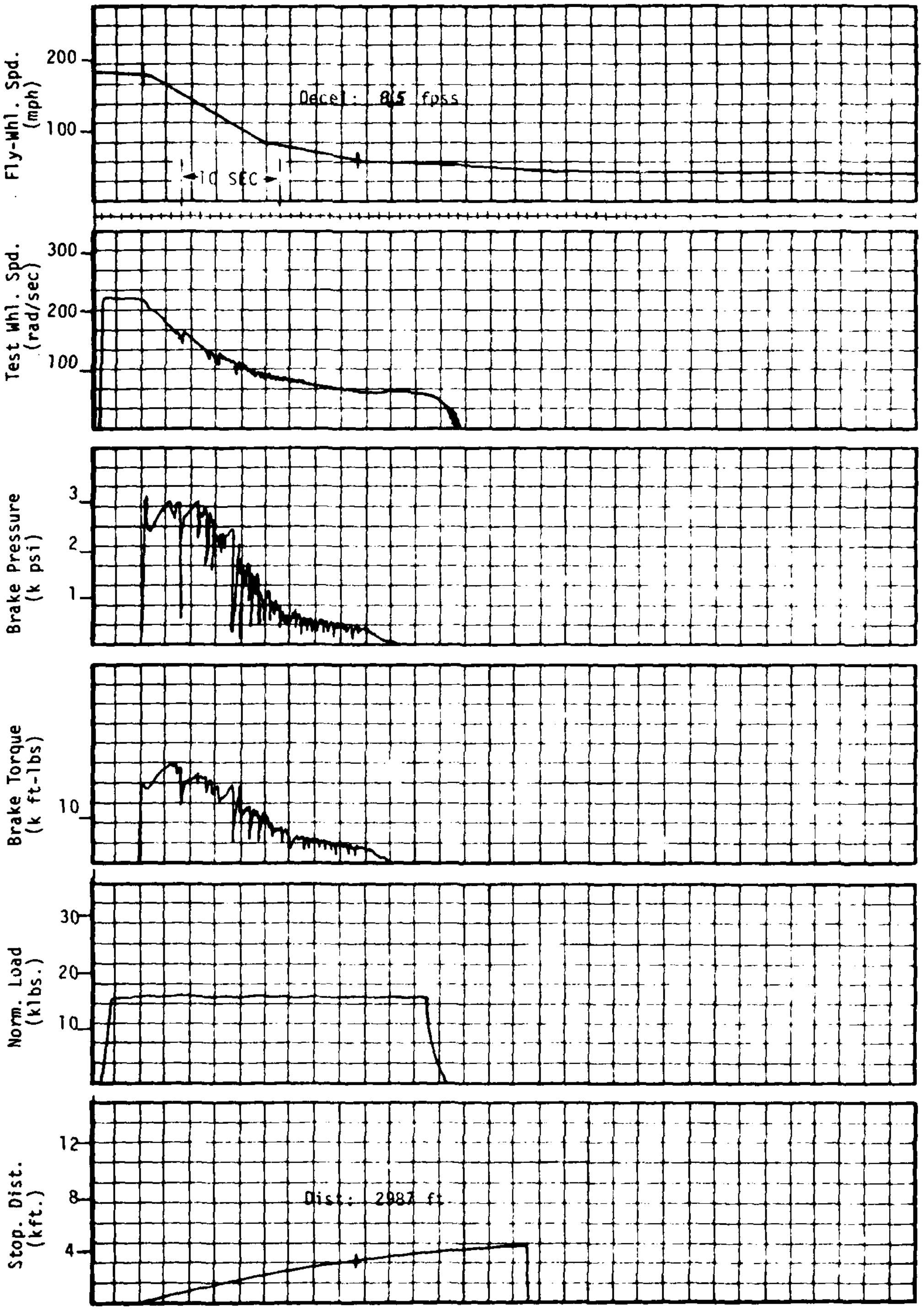


Figure C-41. S/N6A0013(#1-R-2), Siped 3/16" X 7/32", Cyc. 105, 0.5 gpm Water on After Landing

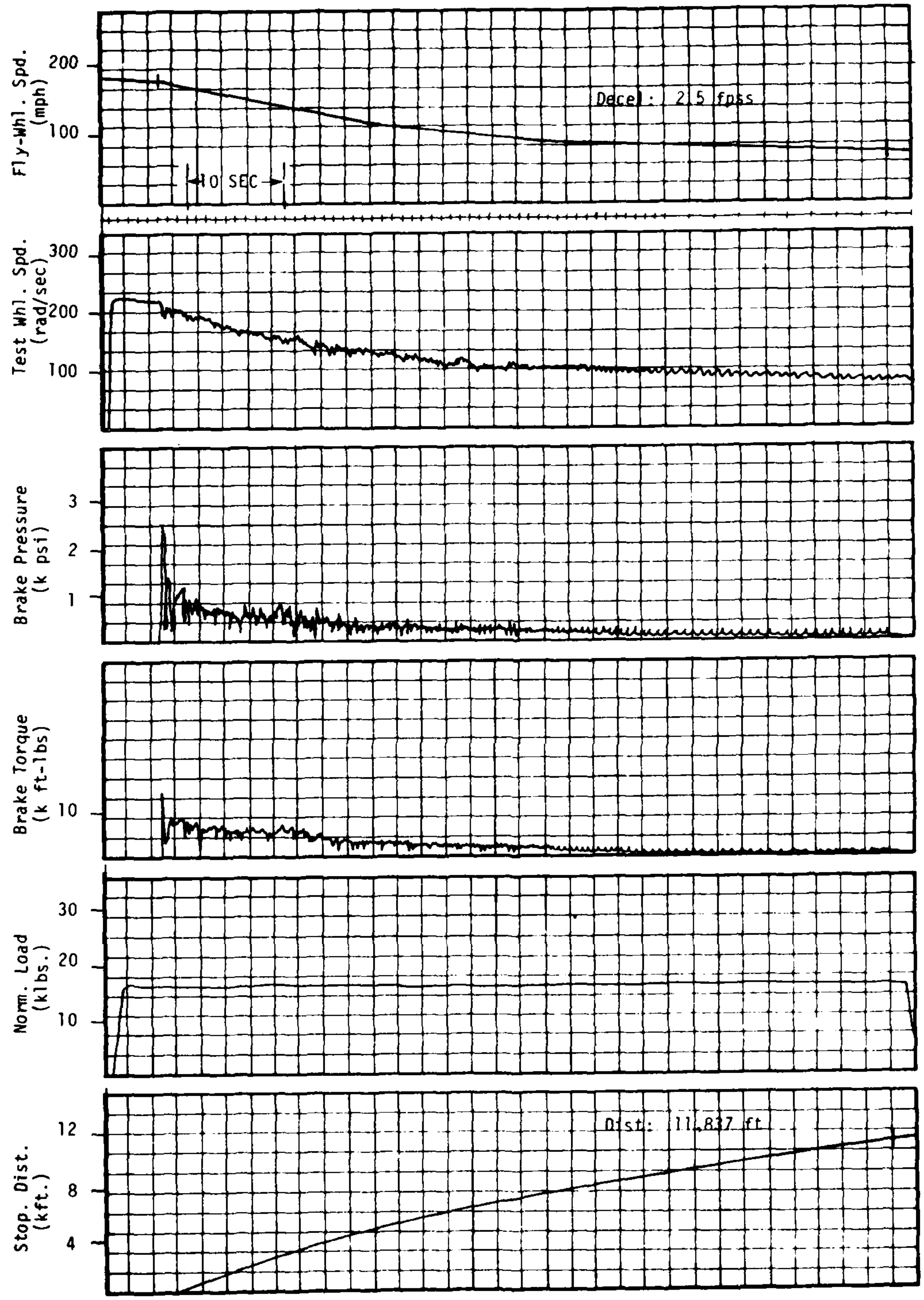


Figure C-42. S/N6A0013(#1-R-2), Siped 3/16" X 7/32", Cyc. 106, 1.0 gpm Water on After Landing

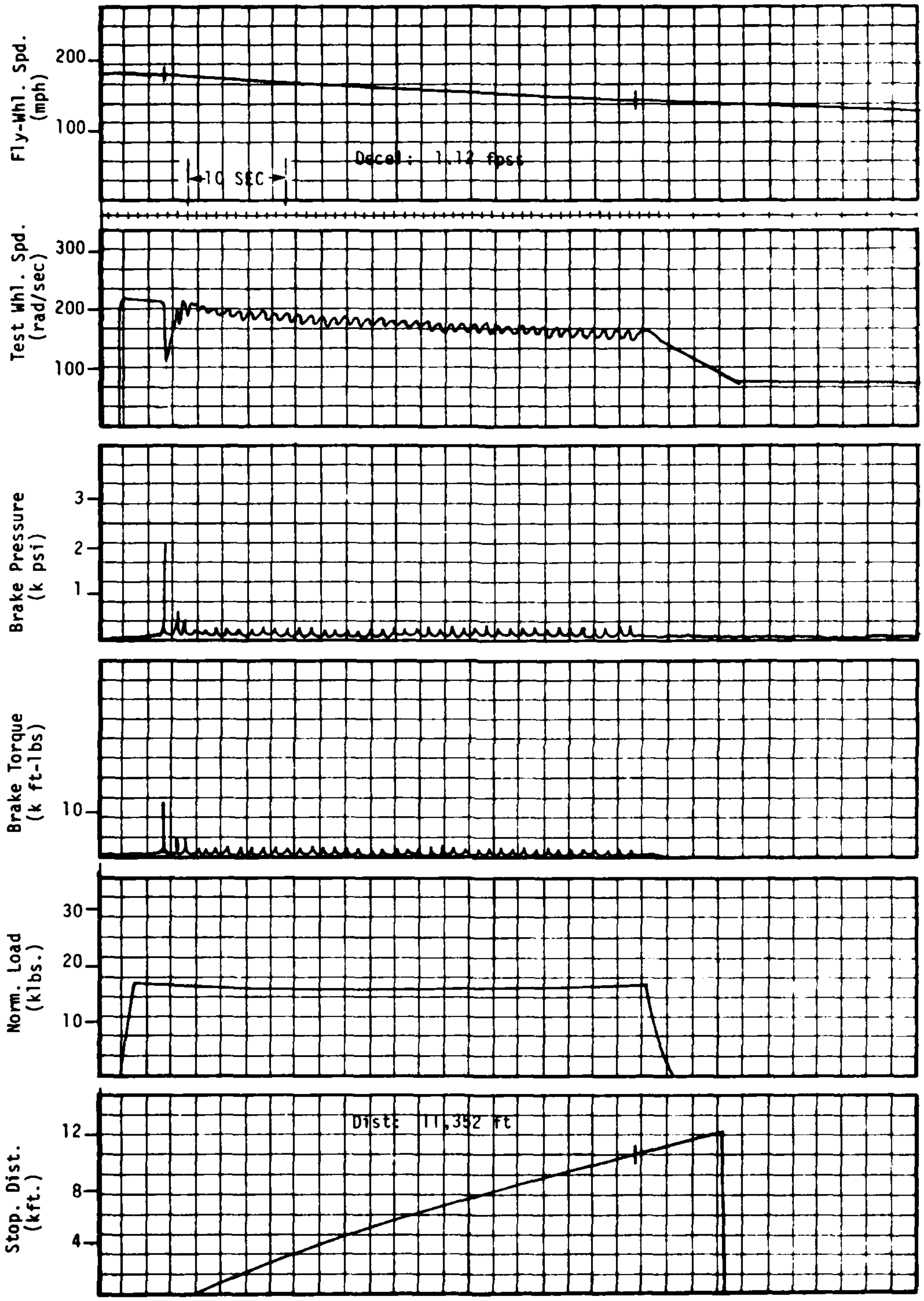


Figure C-43. S/N6A0013(#1-R-2), Siped 3/16" X 7/32", Cyc. 107, 2.0 gpm Water on After Landing

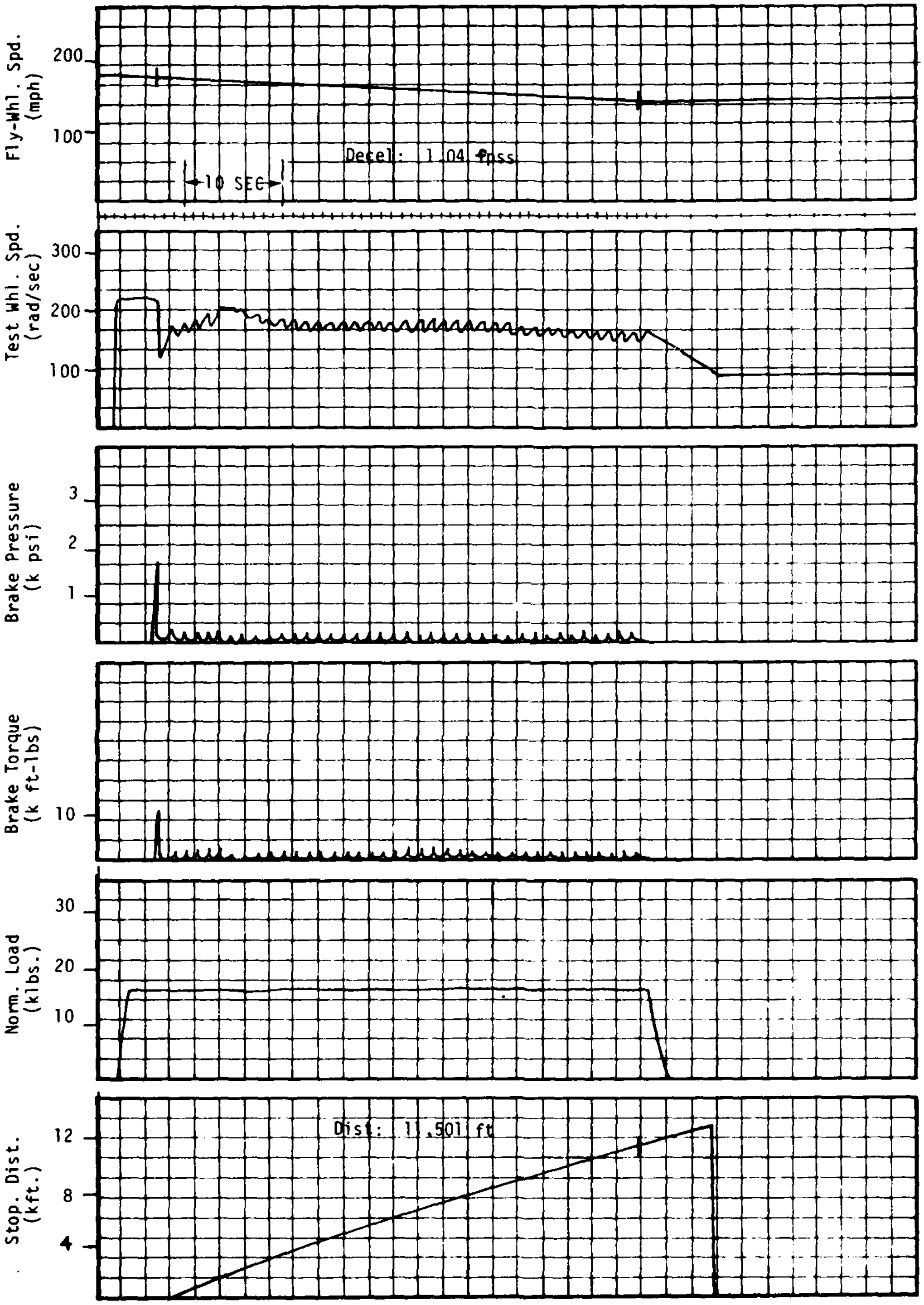


Figure C-44. S/N6A0013(#1-R-2), Siped 3/16" X 7/32", Cyc. 108, 3.0 gpm Water on After Landing

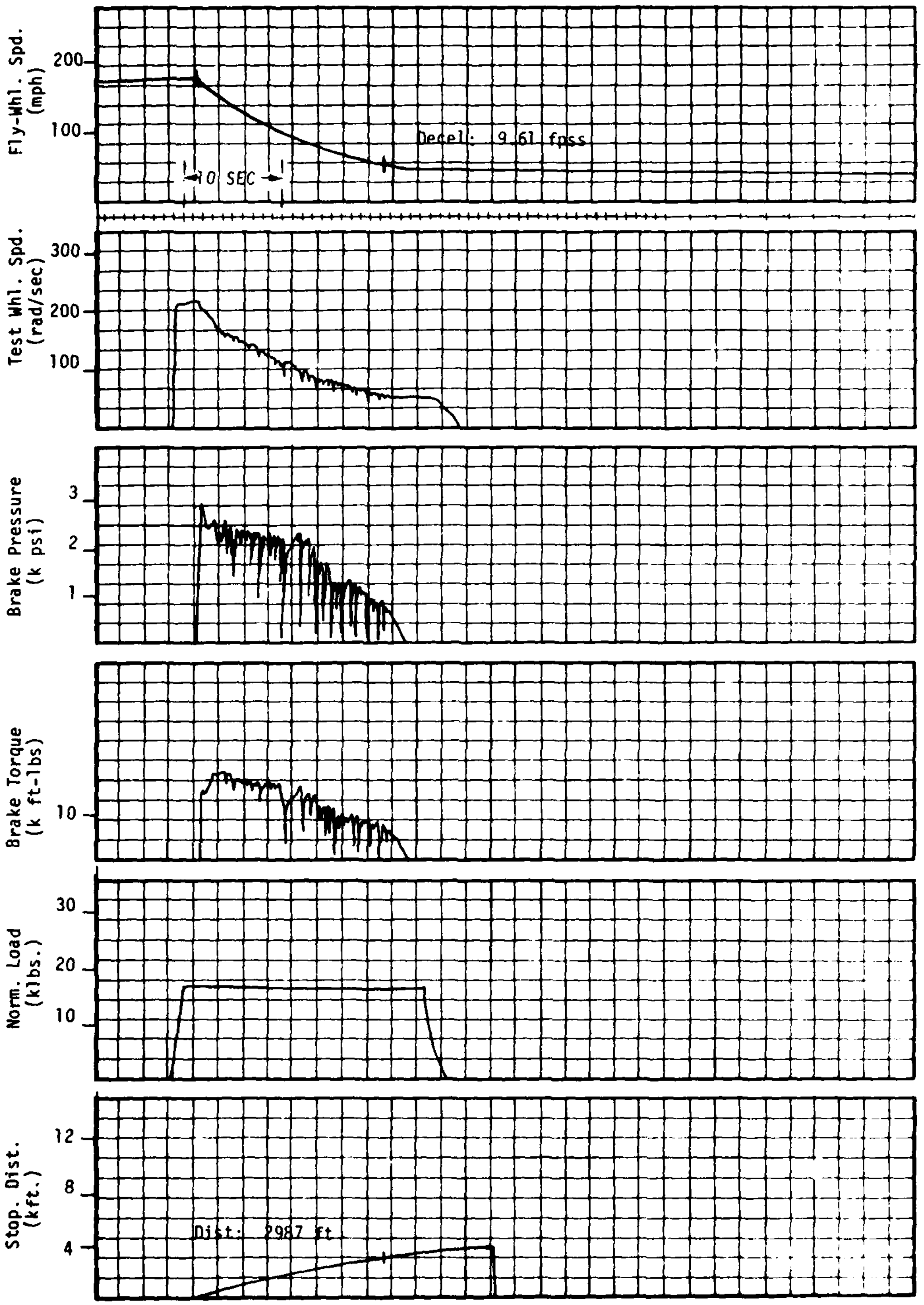


Figure C-45. S/N6A0013(#1-R-2), Siped 3/16" X 7/32", Cyc. 109, 0.5 gpm

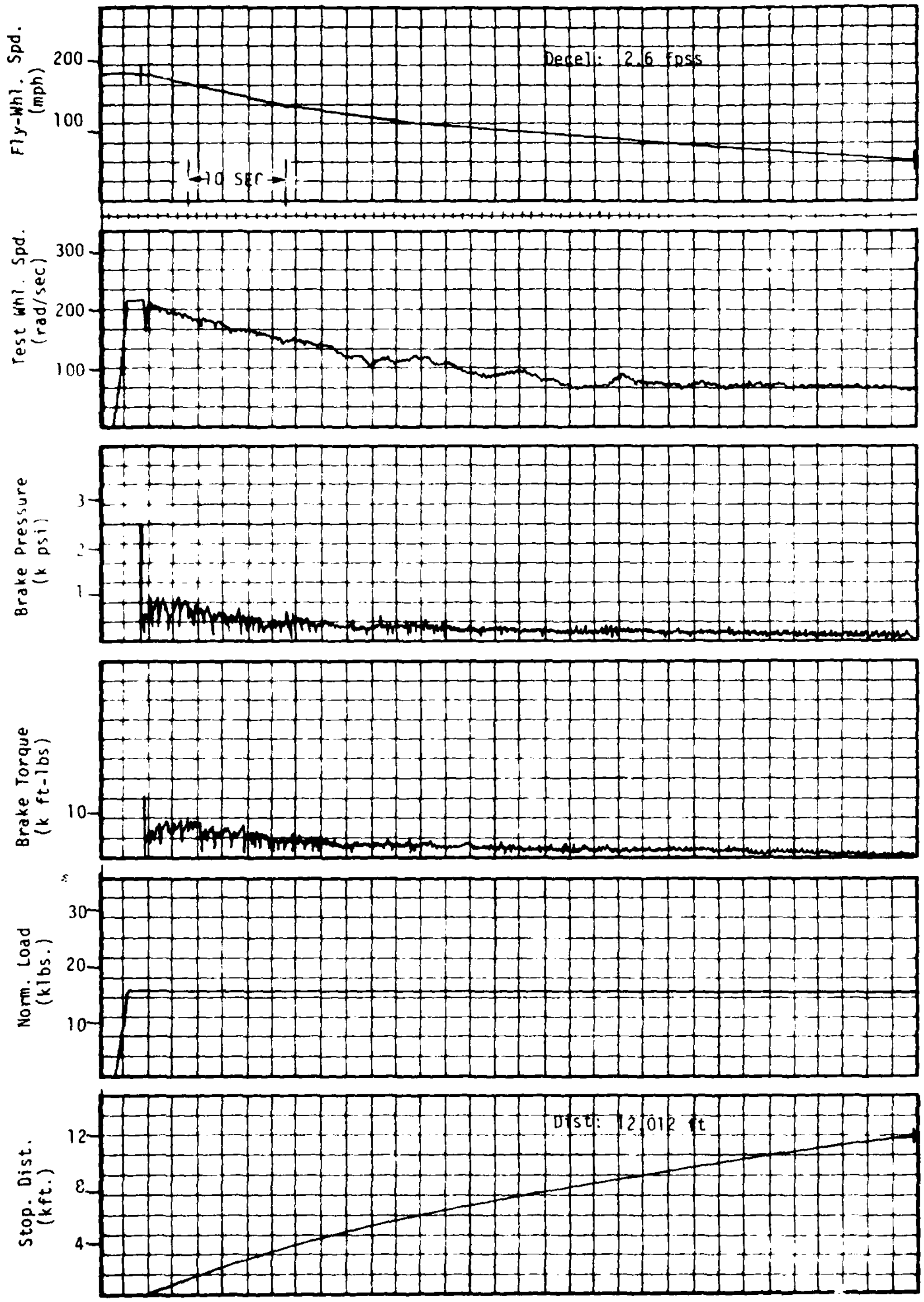


Figure C46. S/N6A0013(#1-R-2), Siped 3/16" X 7/32", Cyc. 110, 1.0 gpm

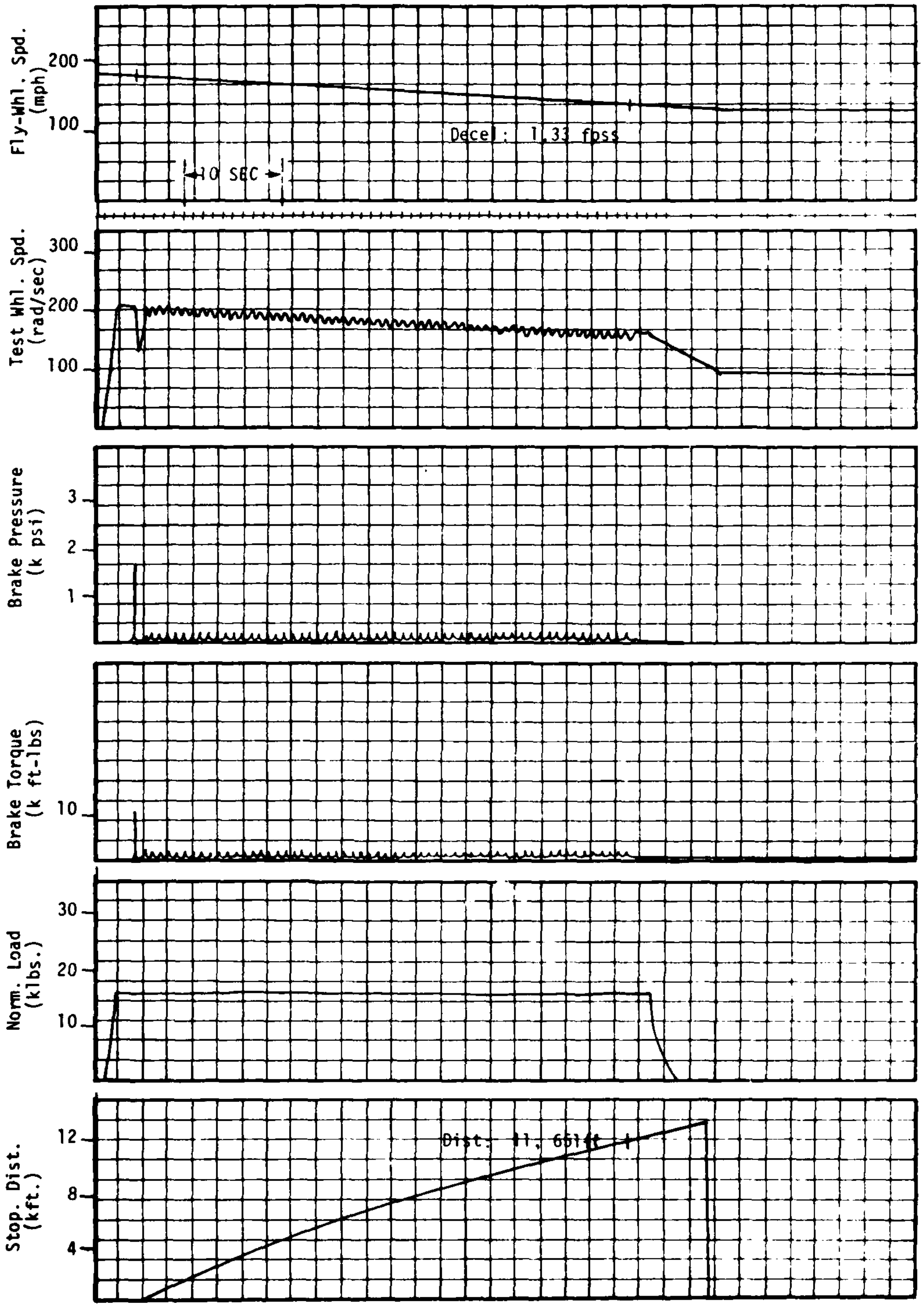


Figure C47. S/N6A0013(#1-R-2), Siped 3/16" X 7/32", Cyc. 111, 2.0 gpm

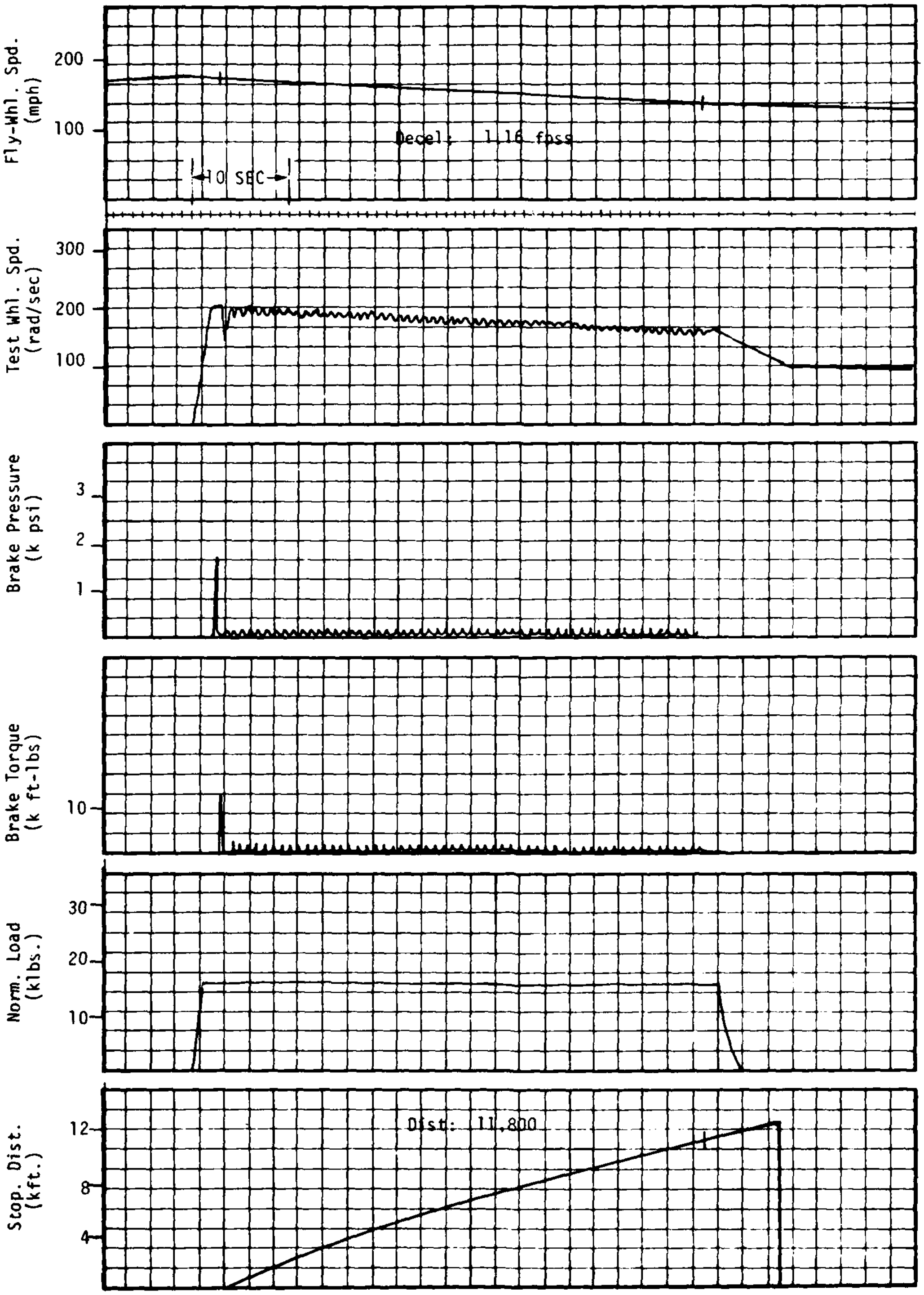


Figure C48. S/N6A0013(#1-R-2), Siped 3/16" X 7/32", Cyc. 112, 3.0 gpm

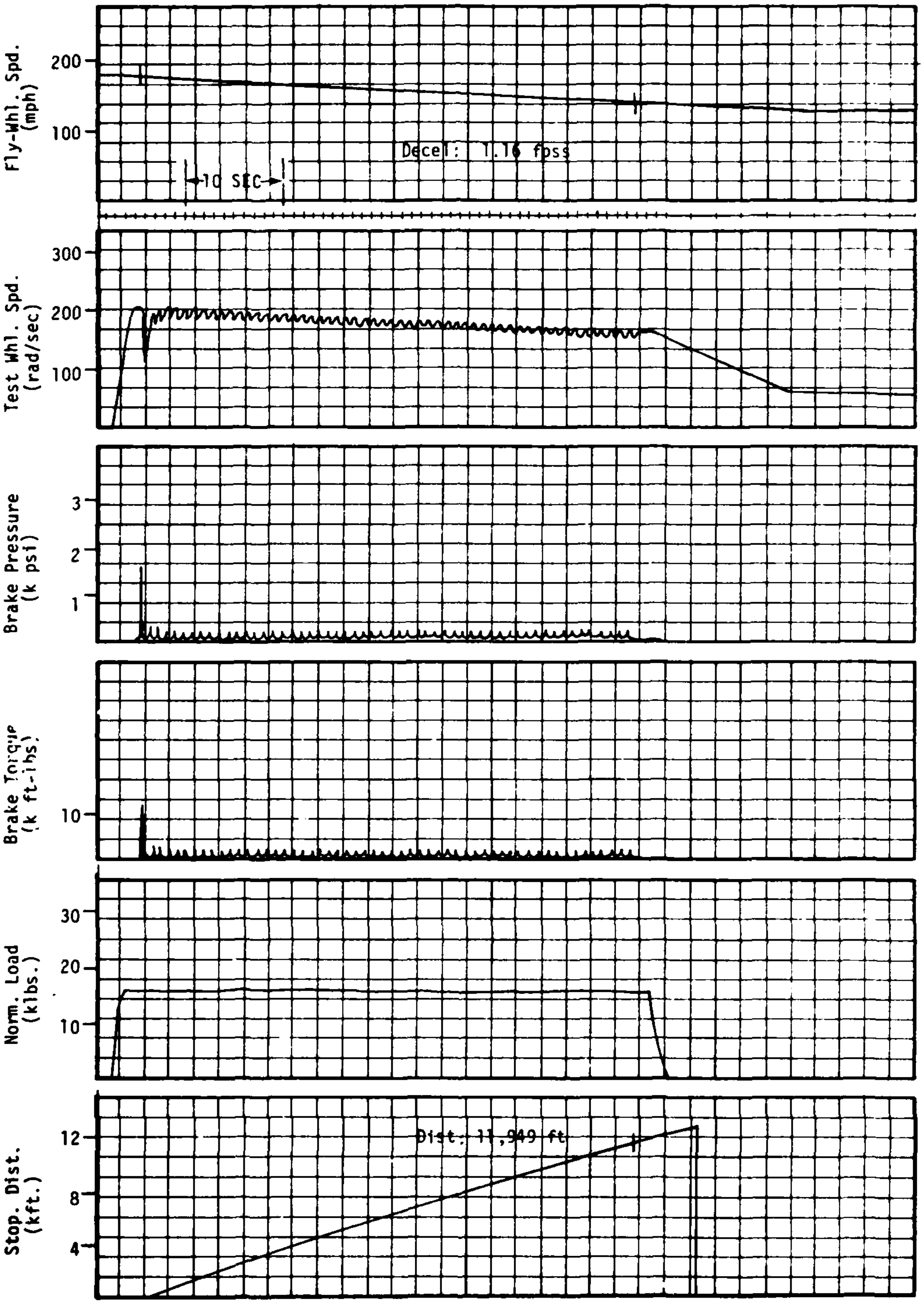


Figure C49. S/N6A0013(#1-R-2), Siped 3/16" X 7/32", Cyc. 113, 4.0 gpm

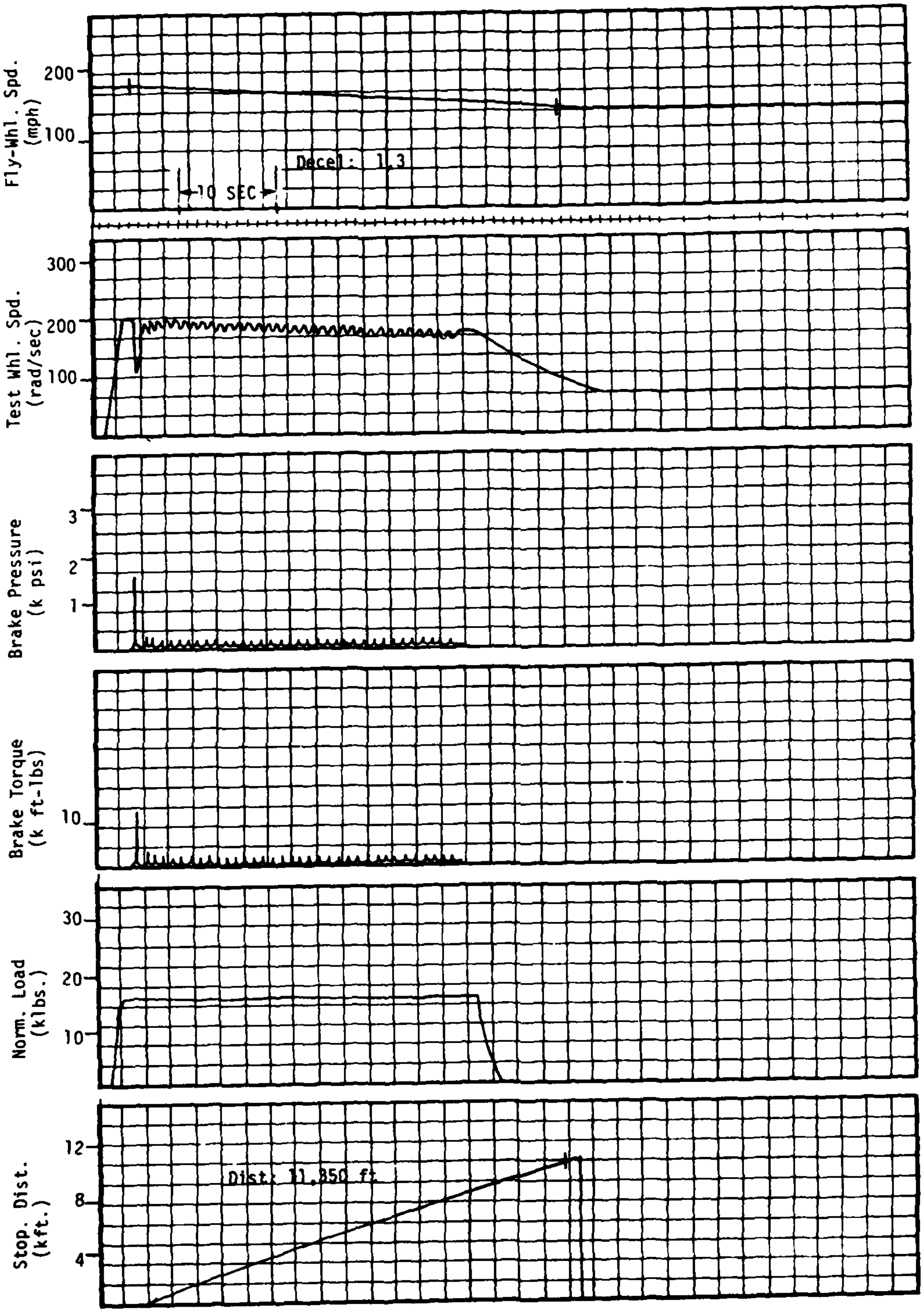


Figure C-50. S/N6A0013(#1-R-2), Siped 3/16" X 7/32", Cyc. 114, 7.5 gpm

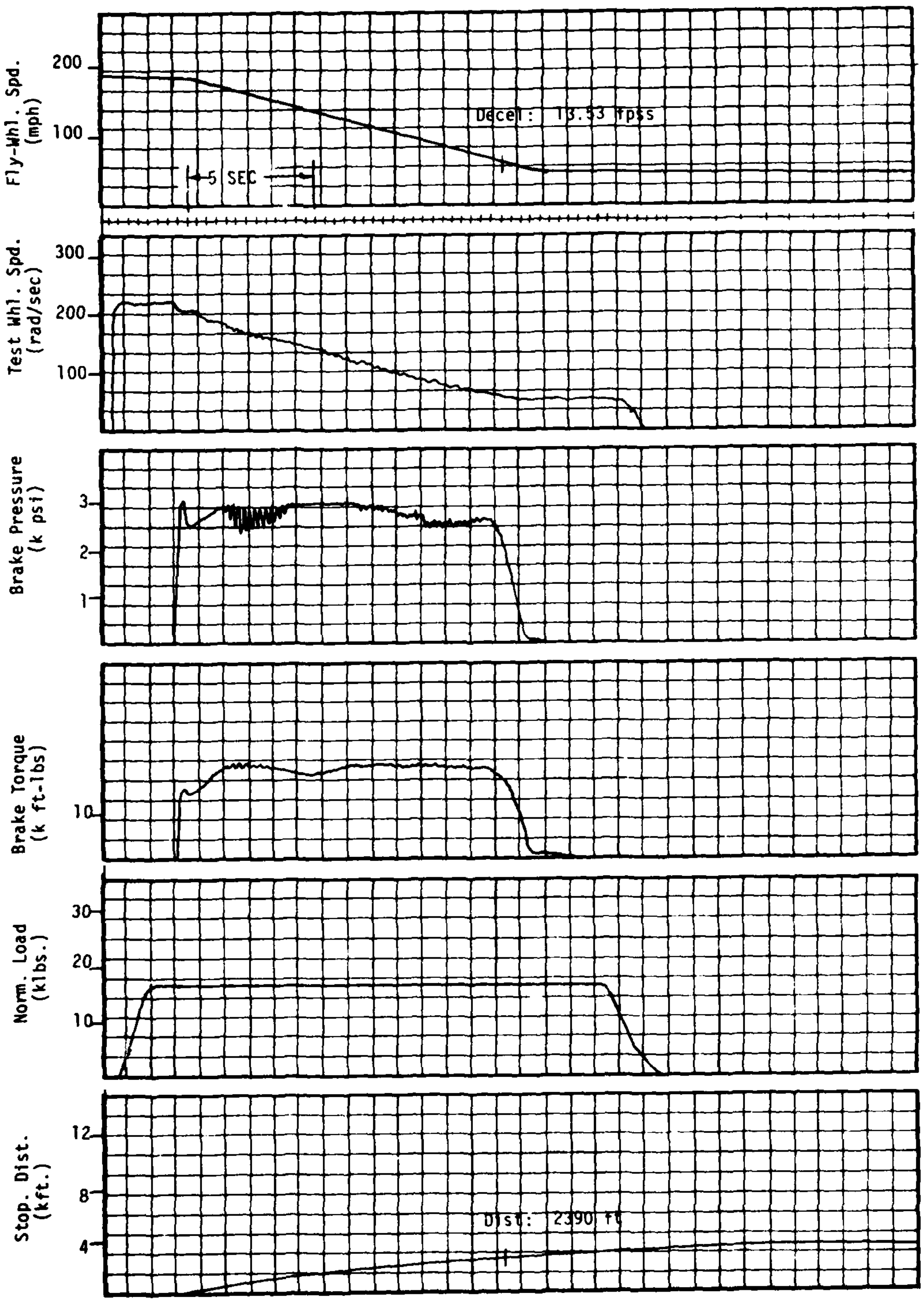


Figure C51. S/N6A0013(#1-R-2), Siped 3/16" X 7/32", Cyc. 115, DRY gpm

APPENDIX D

X-Y PLOTS

FLYWHEEL VELOCITY VS BRAKE STOP DISTANCE

HIGH SPEED BRAKE ANTI-SKID STOPS

192 INCH DYNAMOMETER

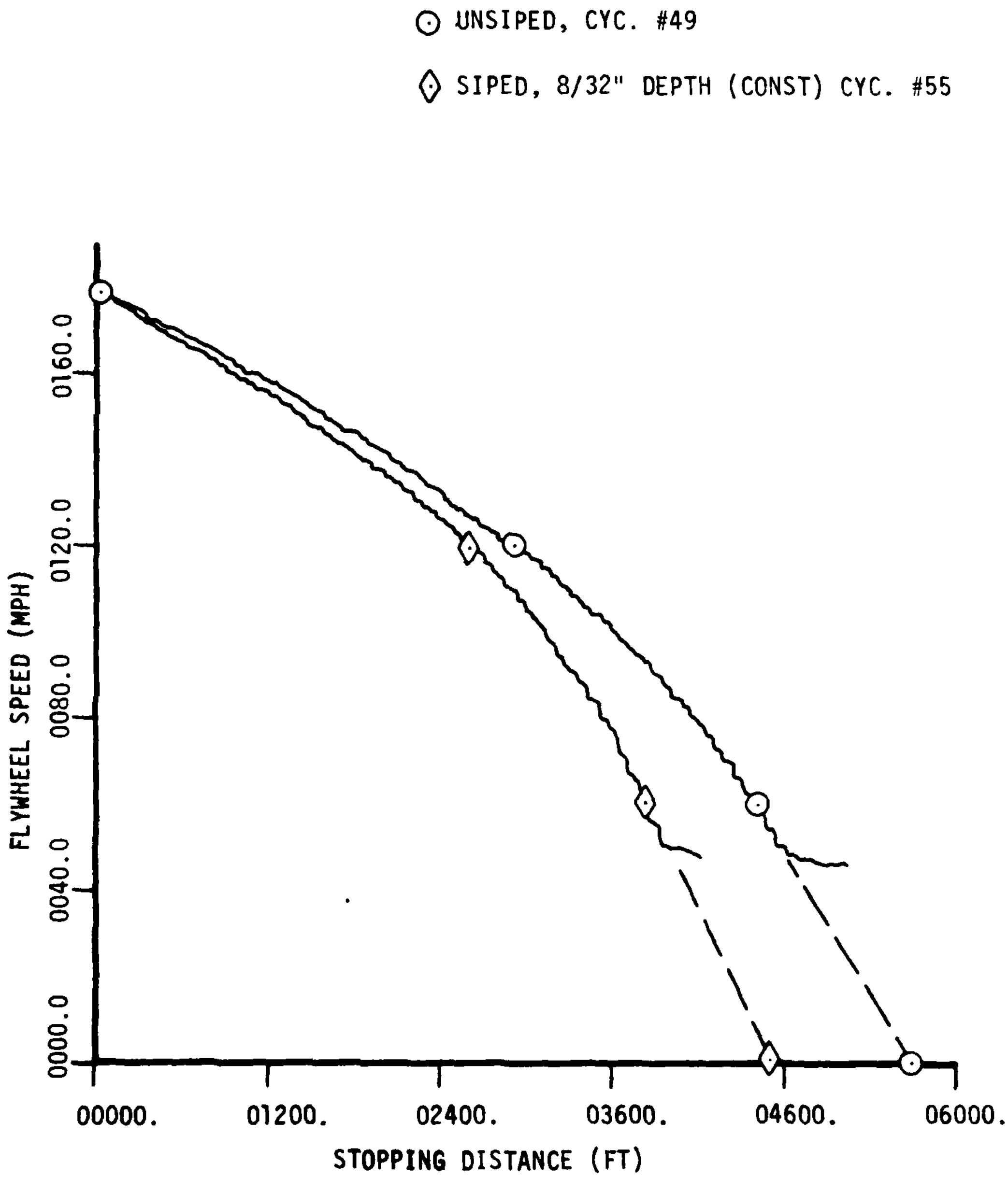


Figure D1. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 25,000 (LBS) Tire Load, 0.5 (GPM) Flow Rate Code Number 18-N

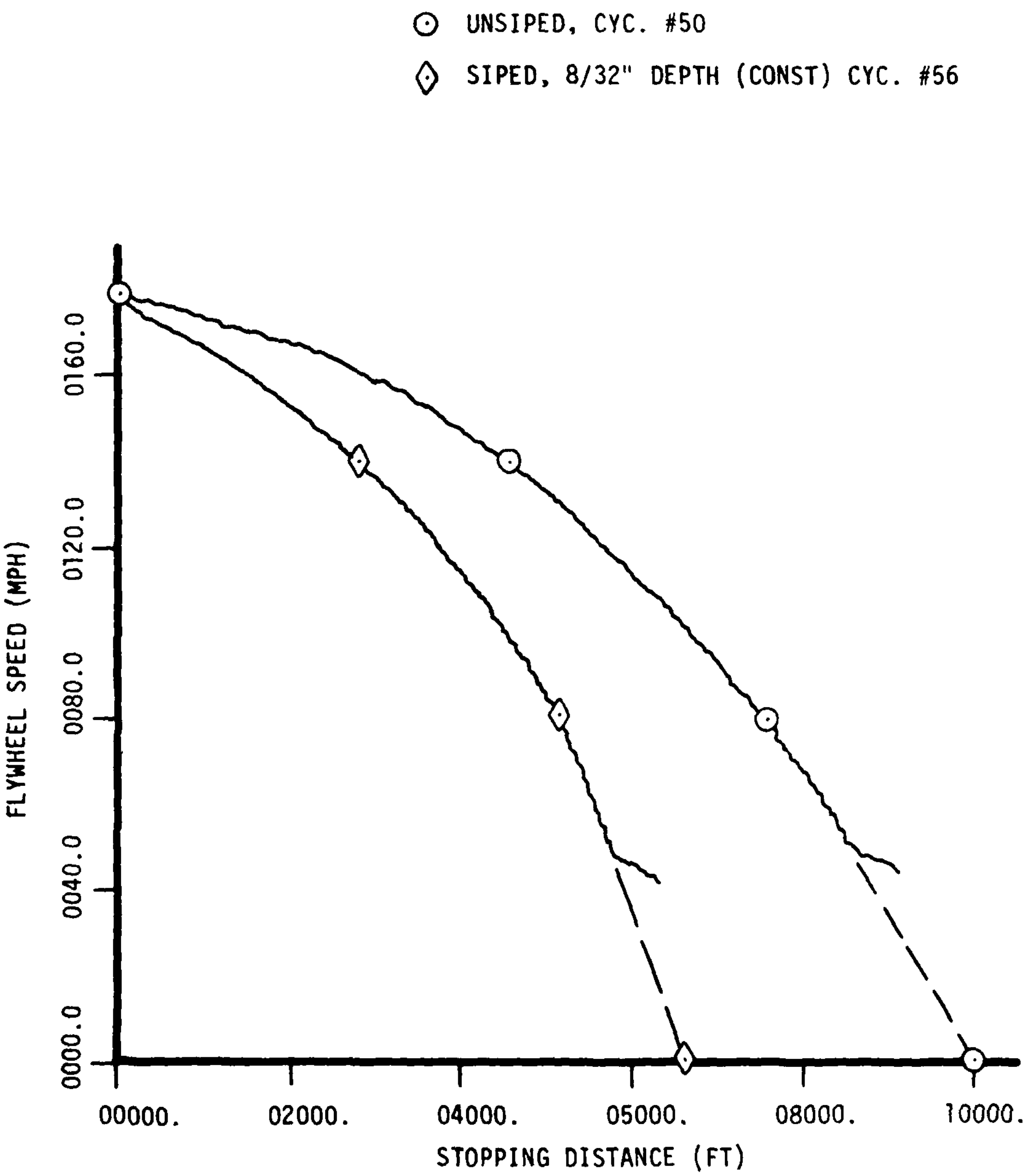


Figure D2. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 25,000 (LBS) Tire Load, 1. (GPM) Flow Rate Code Number 18-N

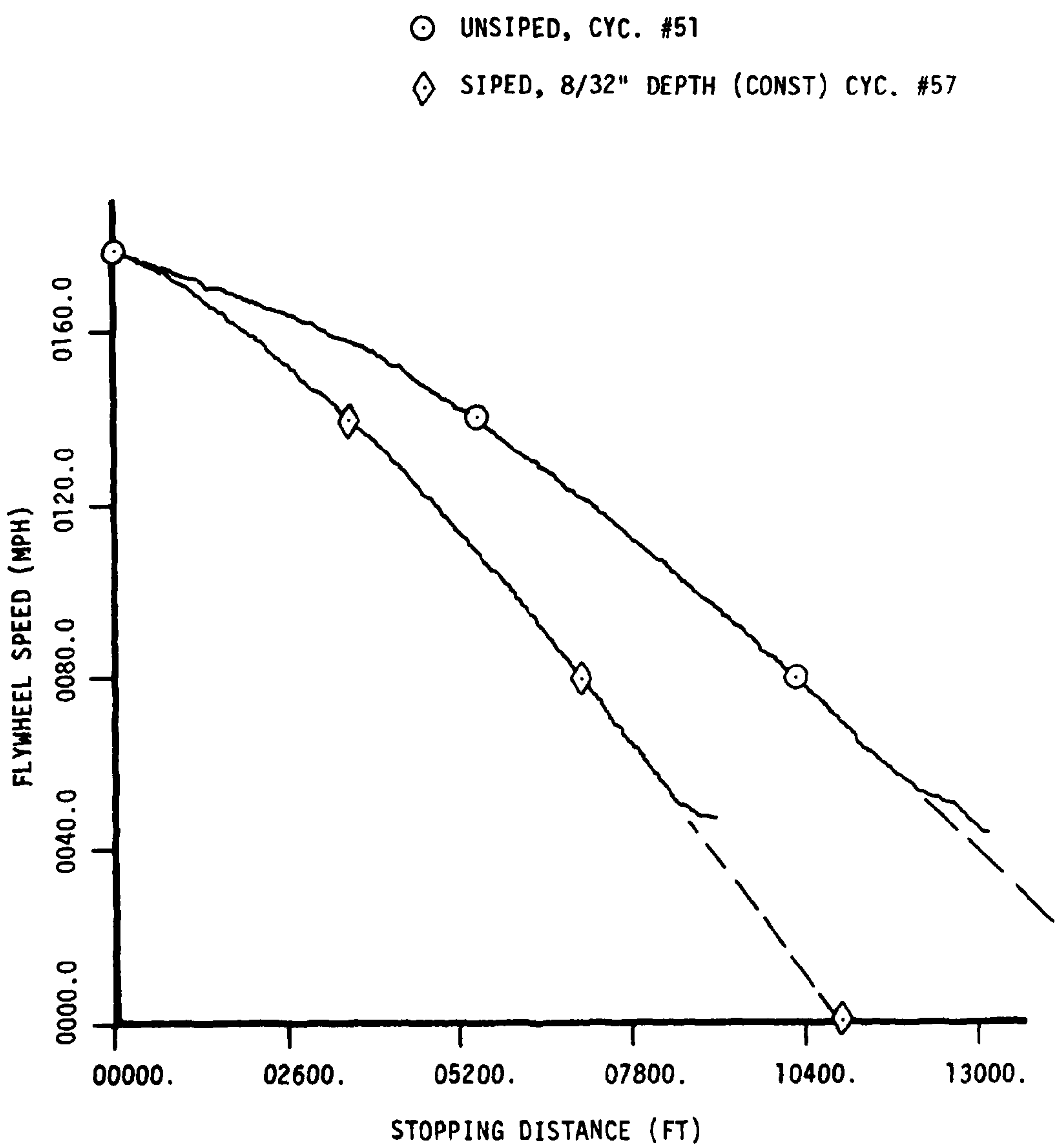


Figure D3. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 25,000 (LBS) Tire Load, 2 (GPM) Flow Rate Code Number 18-N

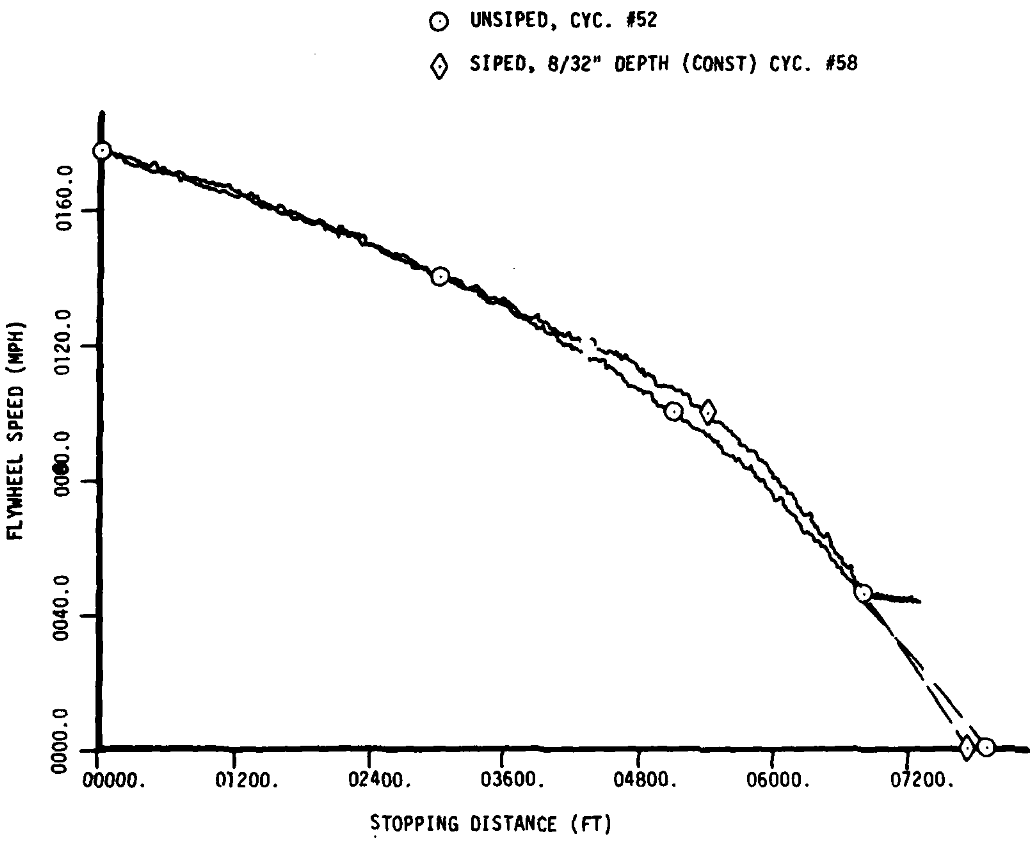


Figure D4. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, 0.5 (GPM) Flow Rate Code Number 18-N

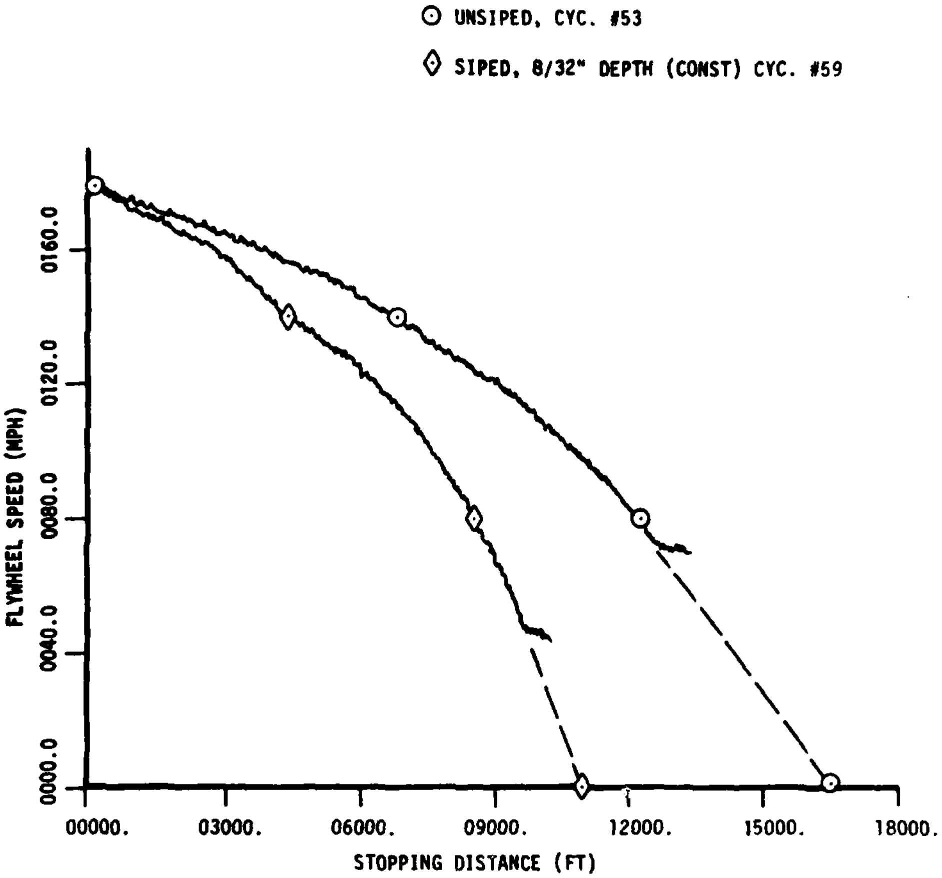


Figure D5. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation
16,000 (LBS) Tire Load, 1 (GPM) Flow Rate Code Number 18-N

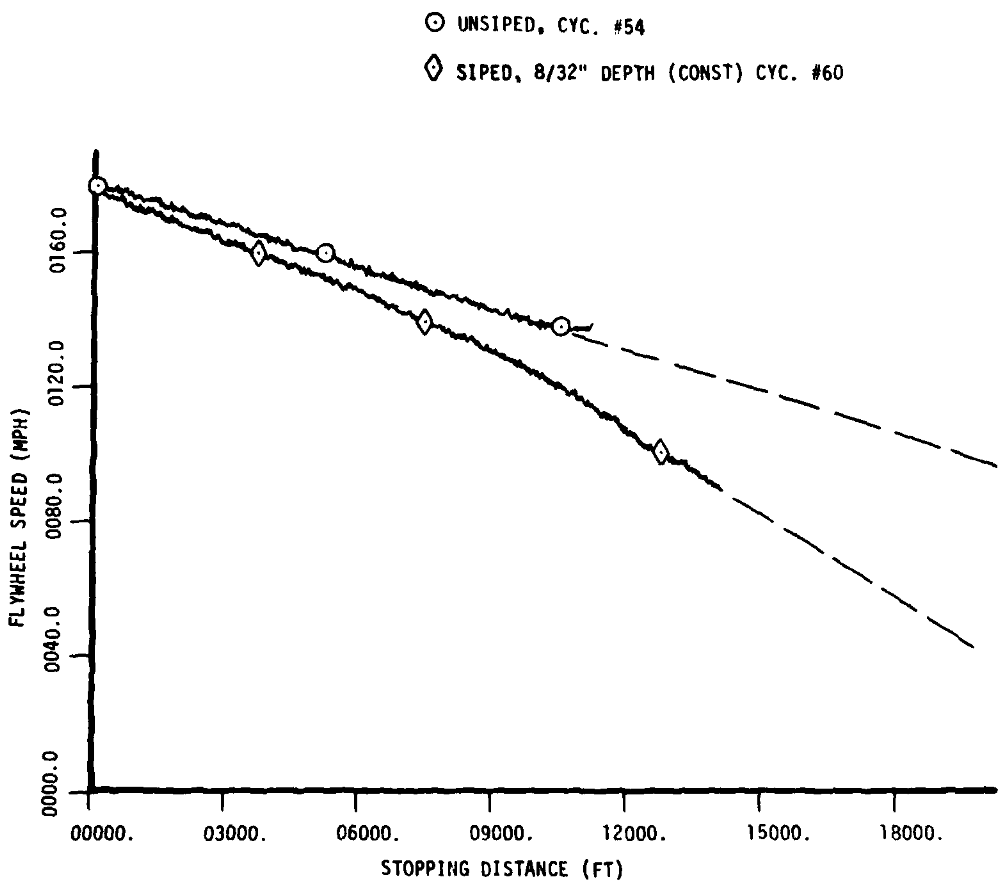


Figure D6. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, 2 (GPM) Flow Rate Code Number 18-N

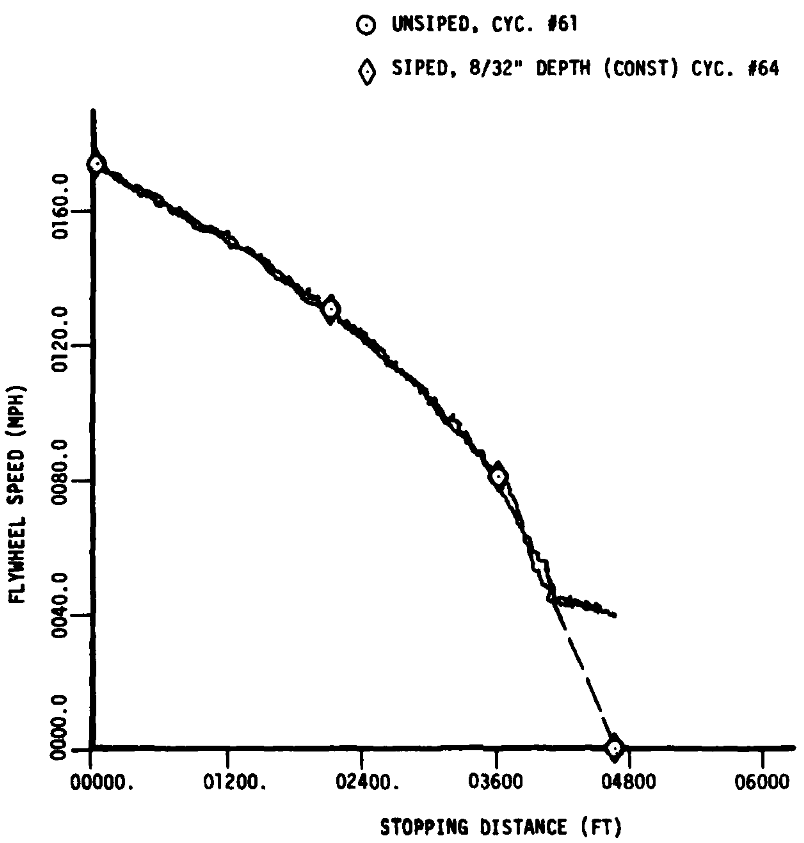


Figure D7. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 25,000 (LBS) Tire Load, 0.5 (GPM) Flow Rate Code Number 20-N

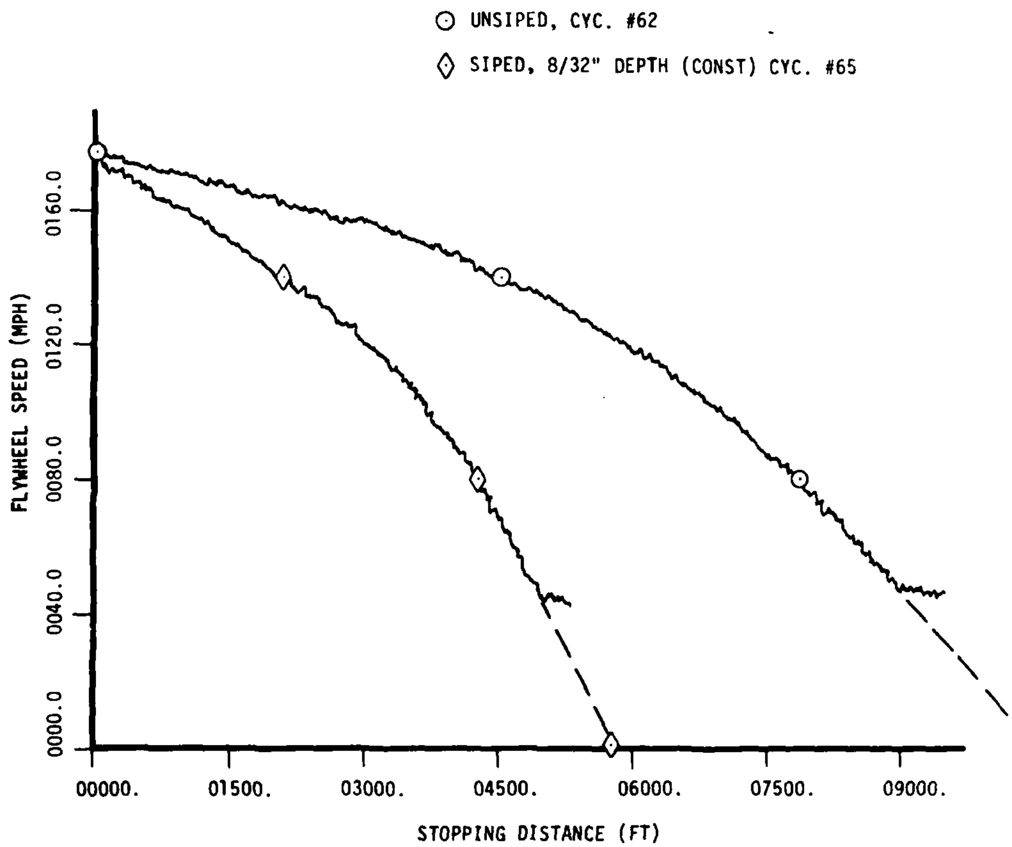


Figure D8. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 25,000 (LBS) Tire Load, 1 (GPM) Flow Rate Code Number 20-N

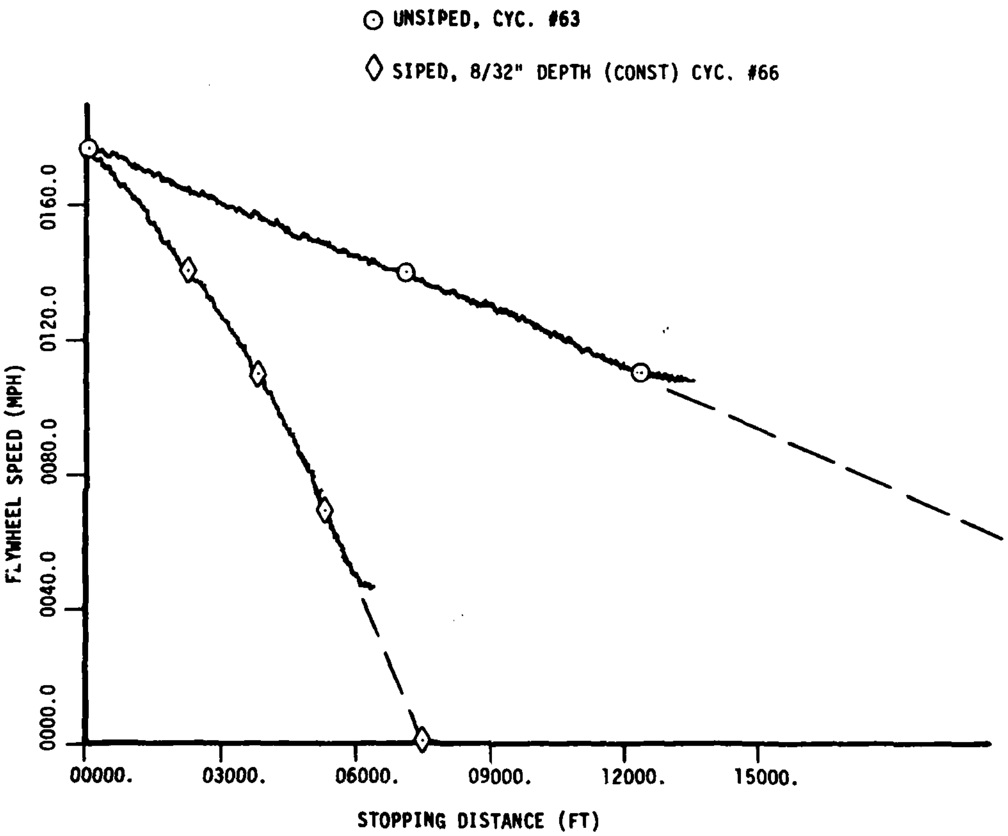


Figure D9. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 25,000 (LBS) Tire Load, 2 (GPM) Flow Rate Code Number 20-N

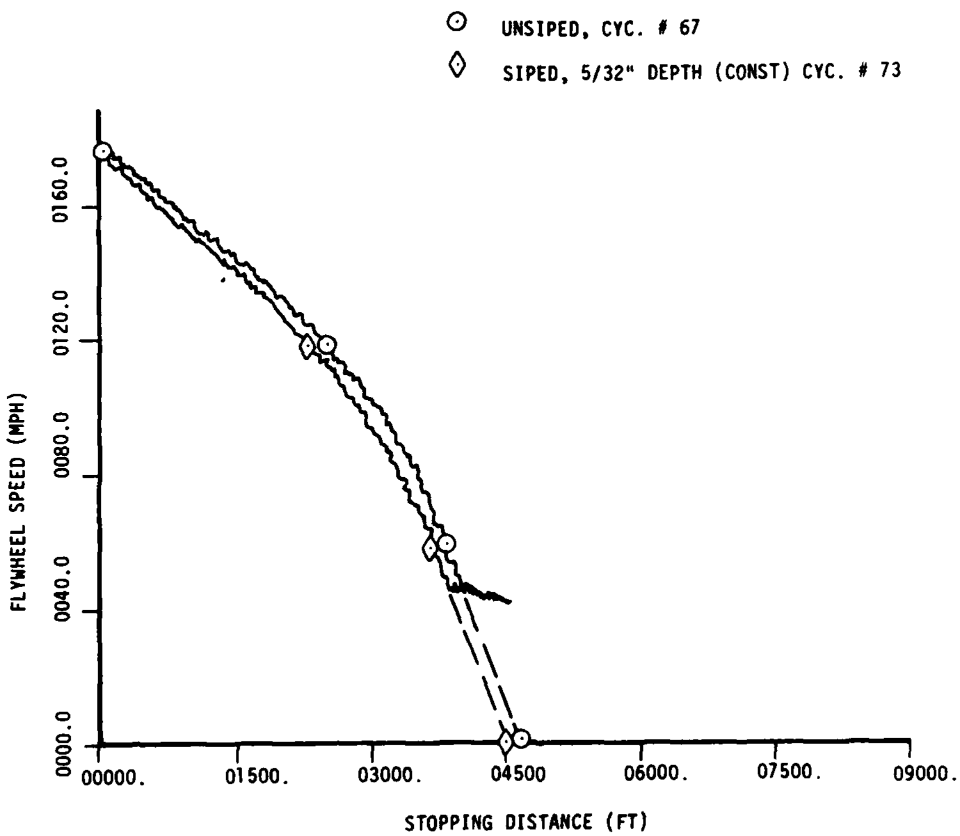


Figure D10. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 25,000 (LBS) Tire Load, 0.5 (GPM) Flow Rate Code Number 21-N

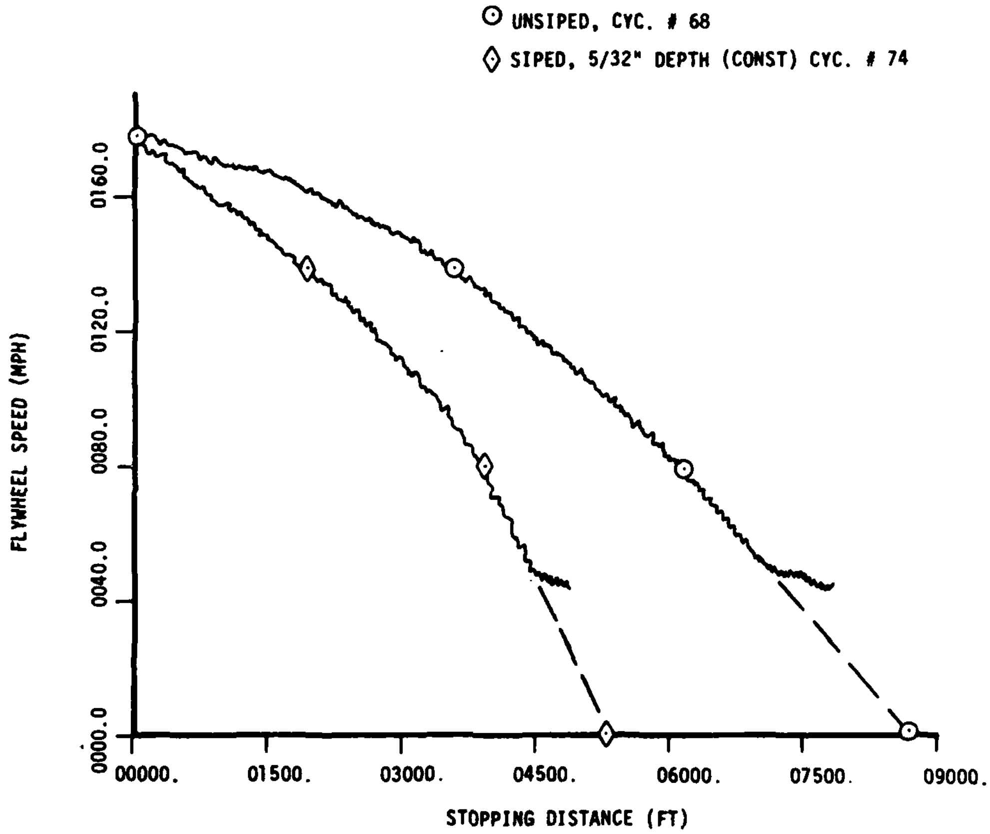


Figure D-11. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 25,000 (LBS) Tire Load, 1 (GPM) Flow Rate Code Number 21-N

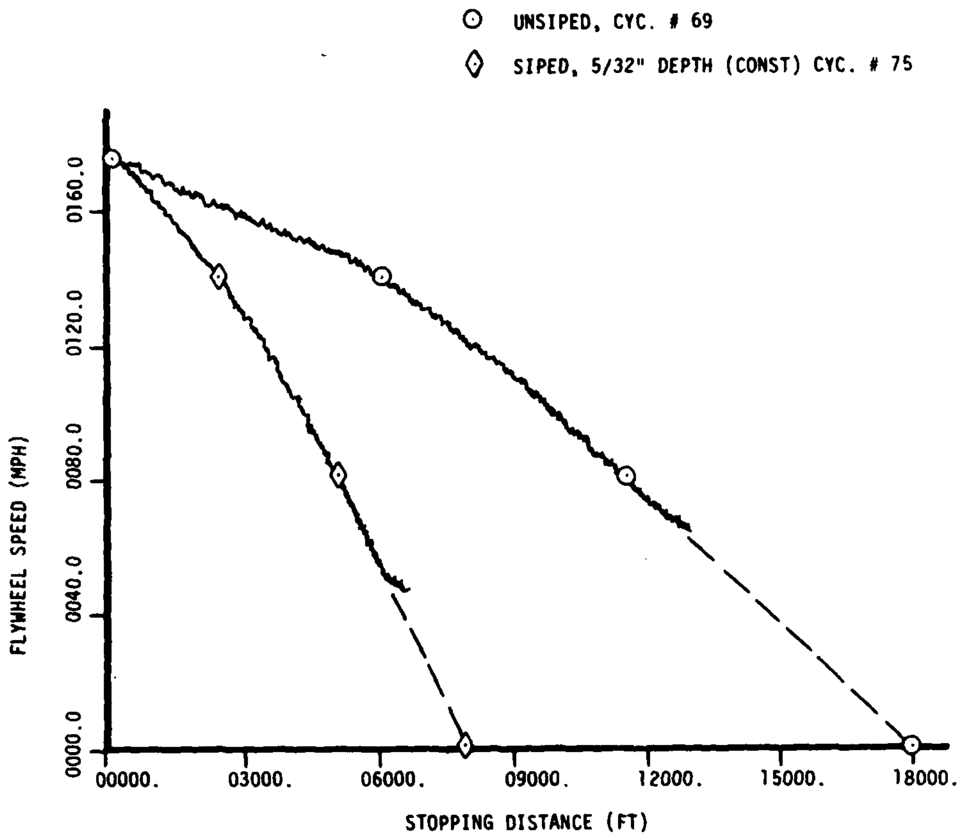


Figure D12. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 25,000 (LBS) Tire Load, 2 (GPM) Flow Rate Code Number 21-N

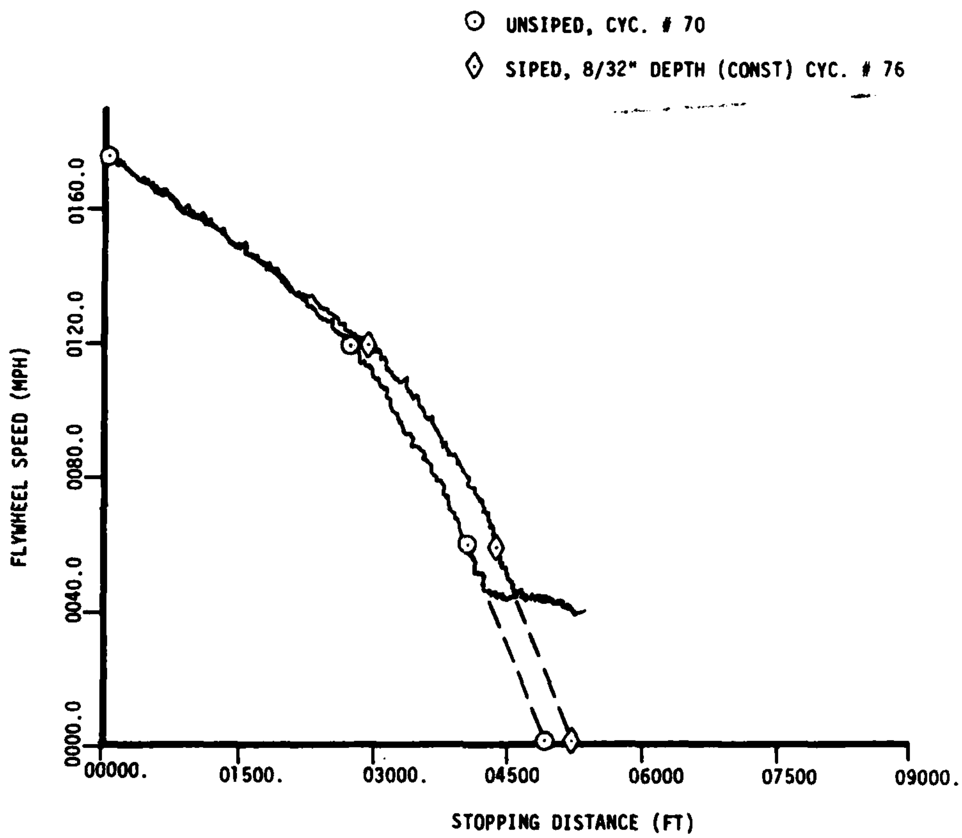


Figure D13. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 25,000 (LBS) Tire Load, 0.5 (GPM) Flow Rate Code Number 22-N

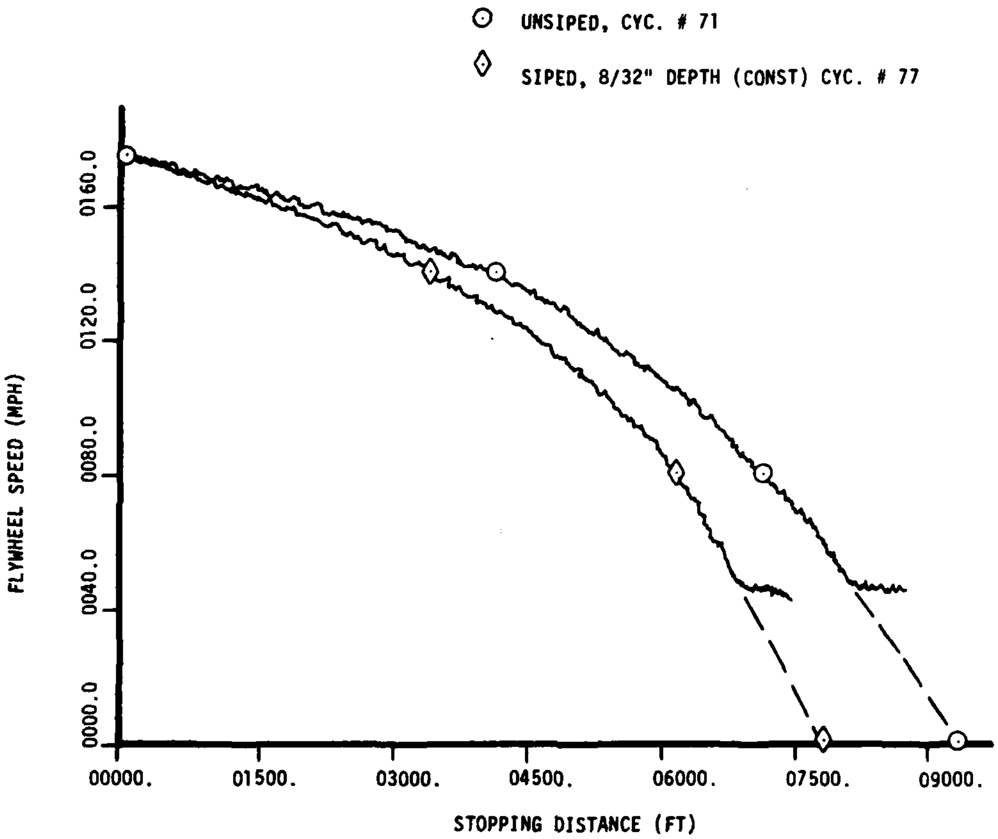


Figure D14. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 25,000 (LBS) Tire Load, 1 (GPM) Flow Rate Code Number 22-N

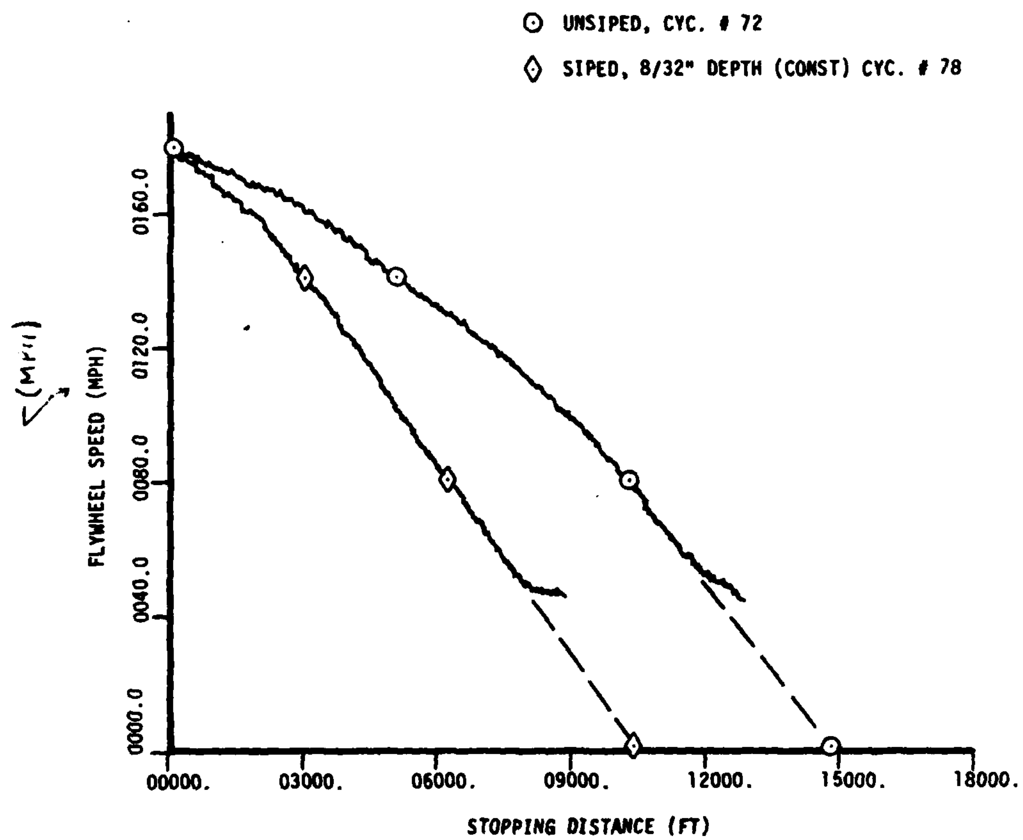


Figure D15. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 25,000 (LBS) Tire Load, 2 (GPM) Flow Rate Code Number 22-N

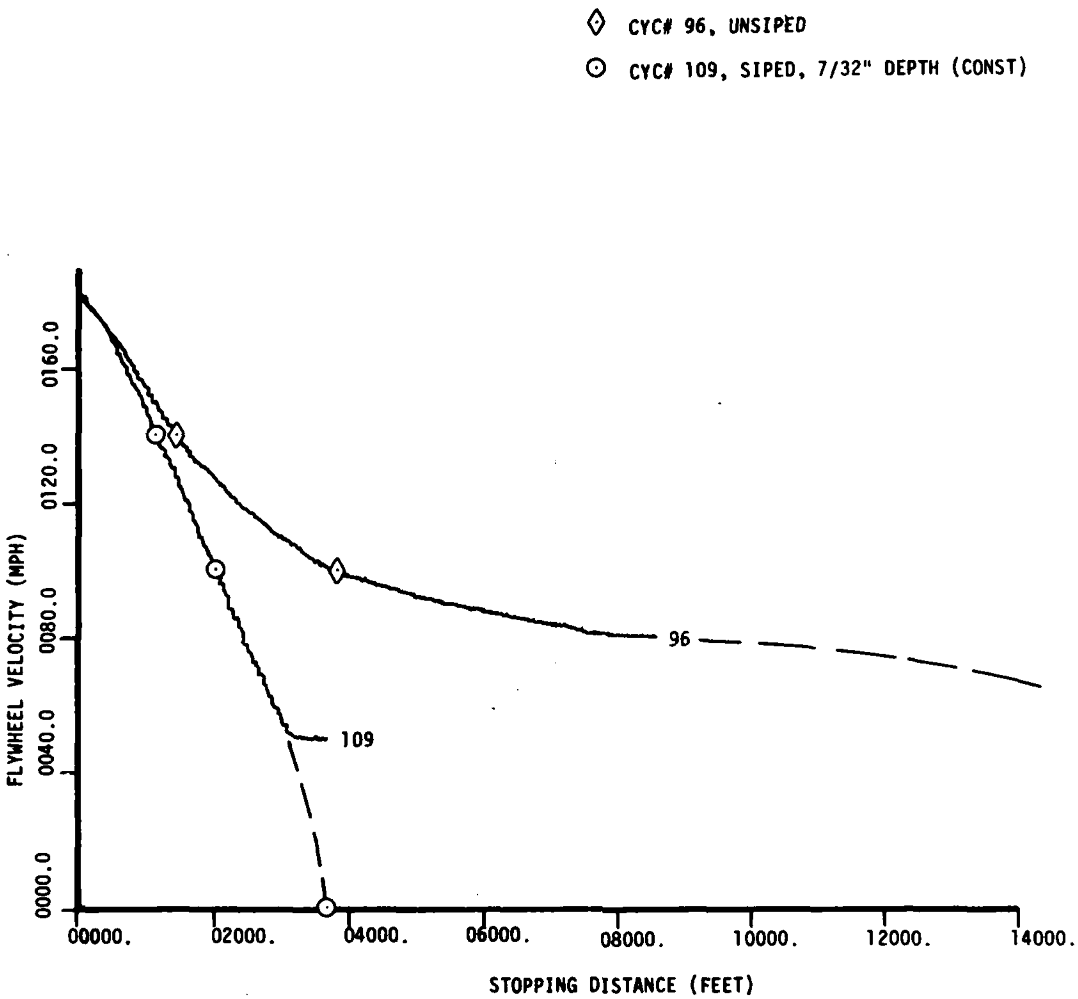


Figure D16. Velocity vs Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 LBS Tire Load, 0.5 (GPM) Flow Rate Code Number 1-R-2

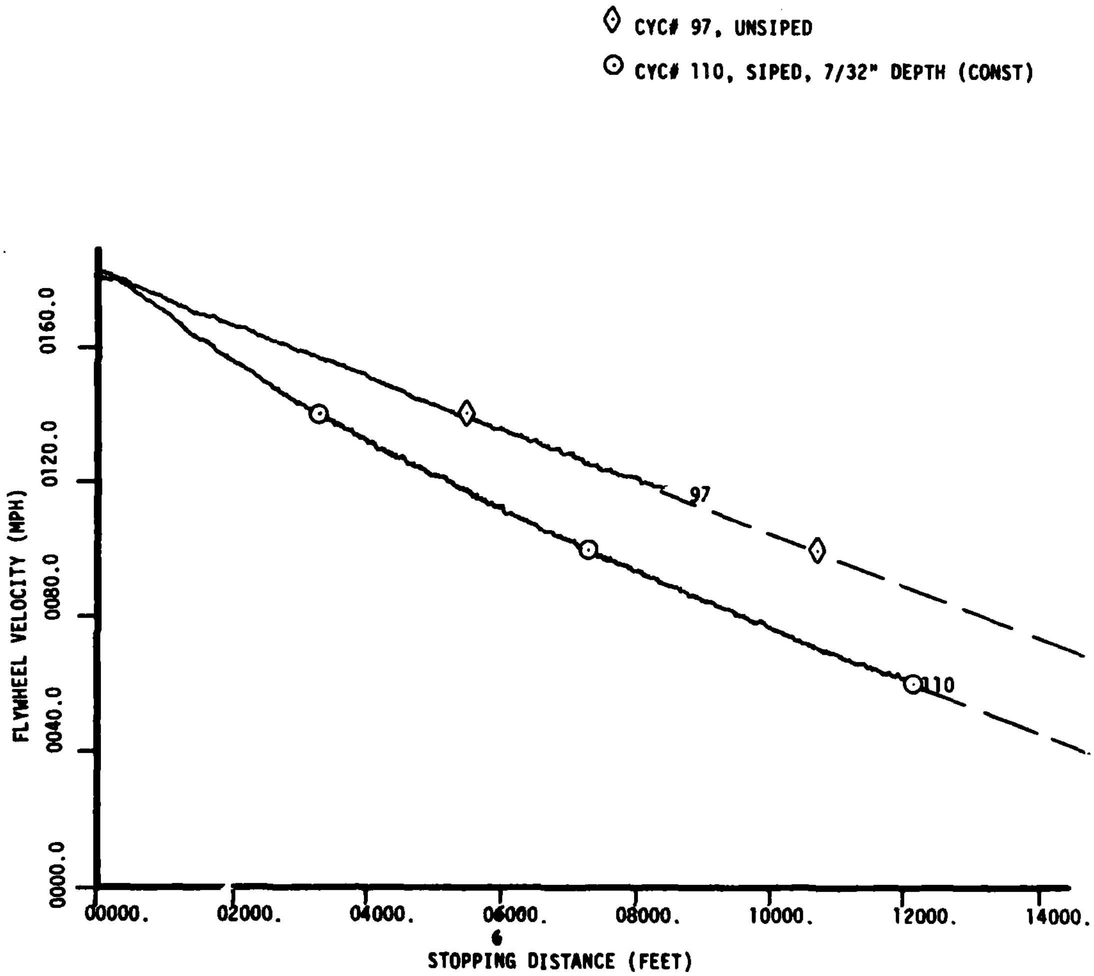


Figure D17. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, 1.0 (GPM) Flow Rate Code Number 1-R-2

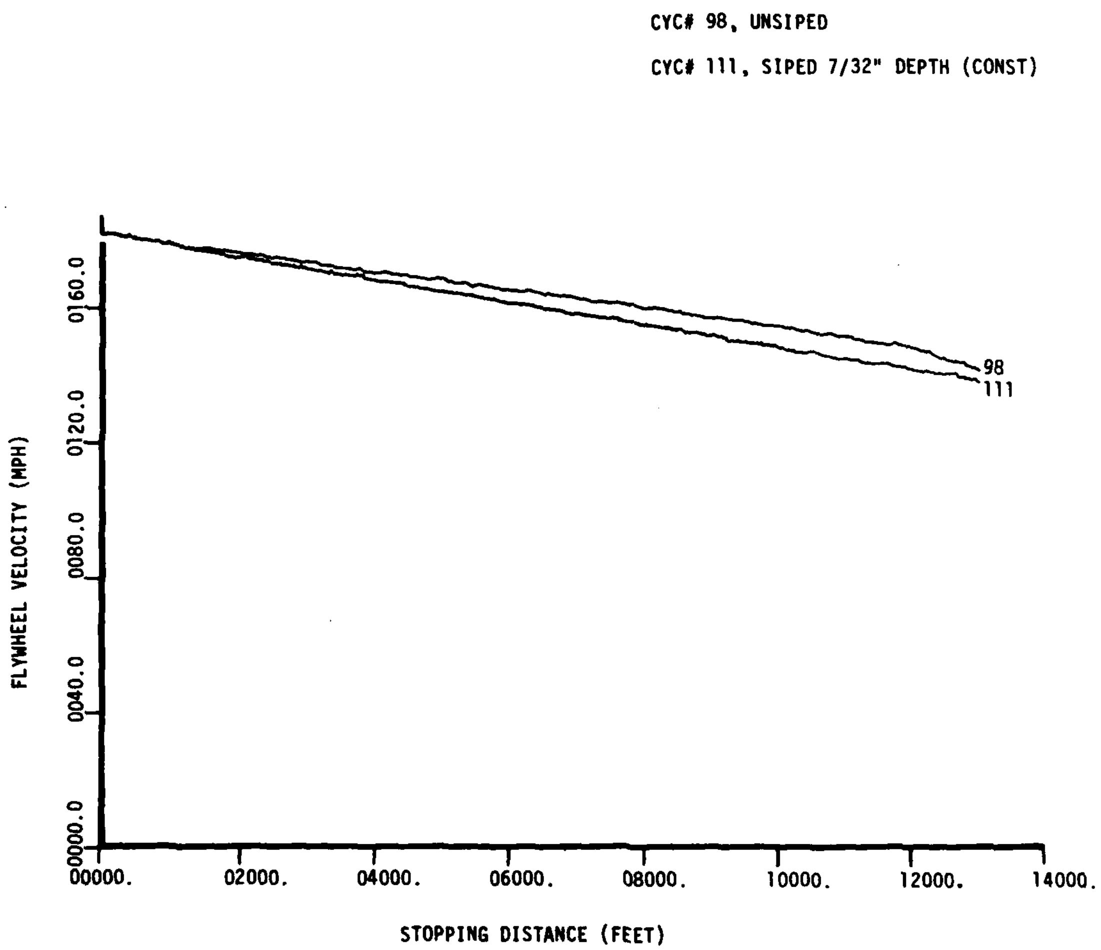


Figure D18. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evalution
16,000 (LBS) Tire Load, 2.0 (GPM) Flow Rate Code Number 1-R-2

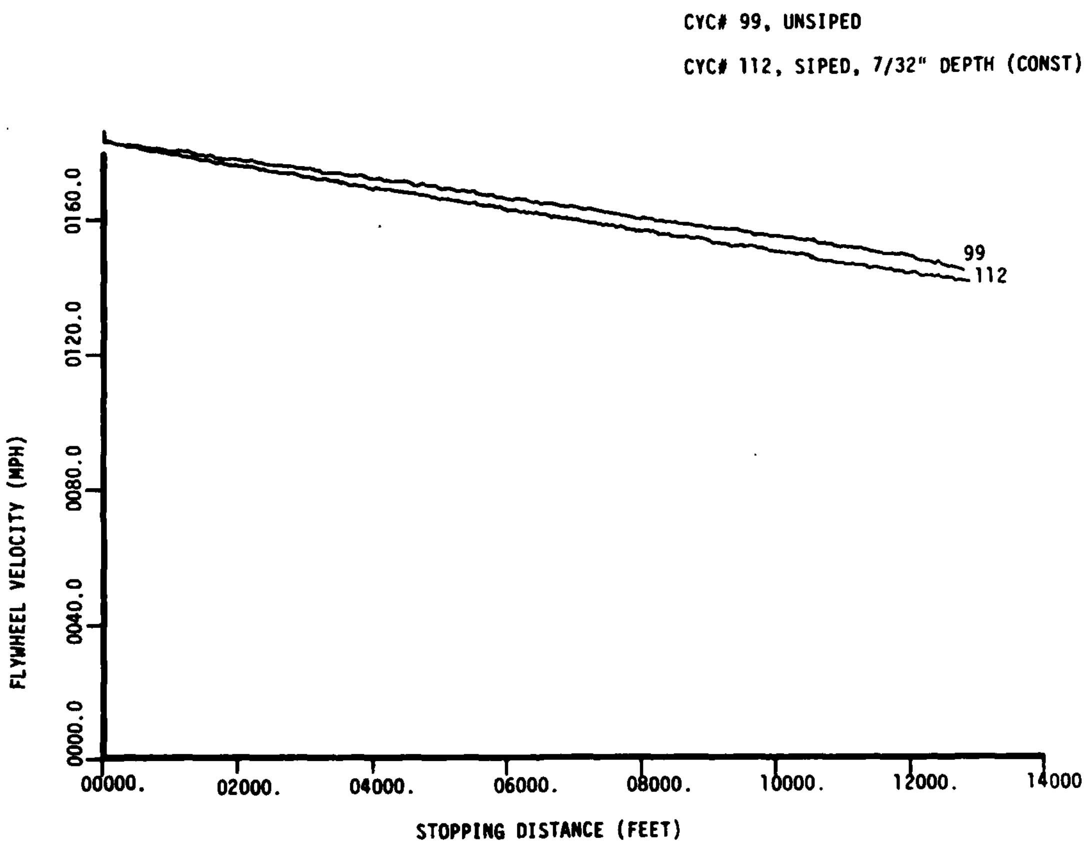


Figure D19. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation
16,000 (LBS) Tire Load, 3.0 (GPM) Flow Rate Code Number 1-R-2

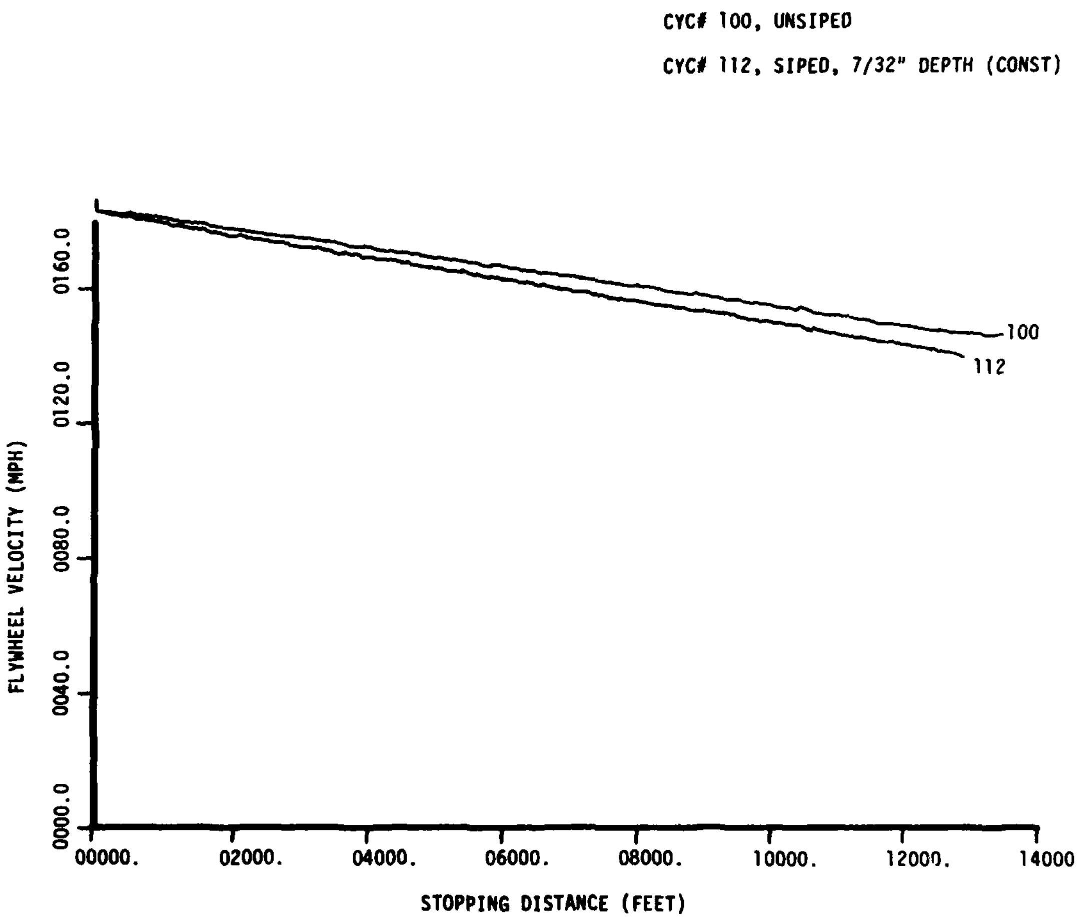


Figure D20. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation
16,000 (LBS) Tire Load, 3.0 (GPM) Flow Rate Code Number 1-R-2

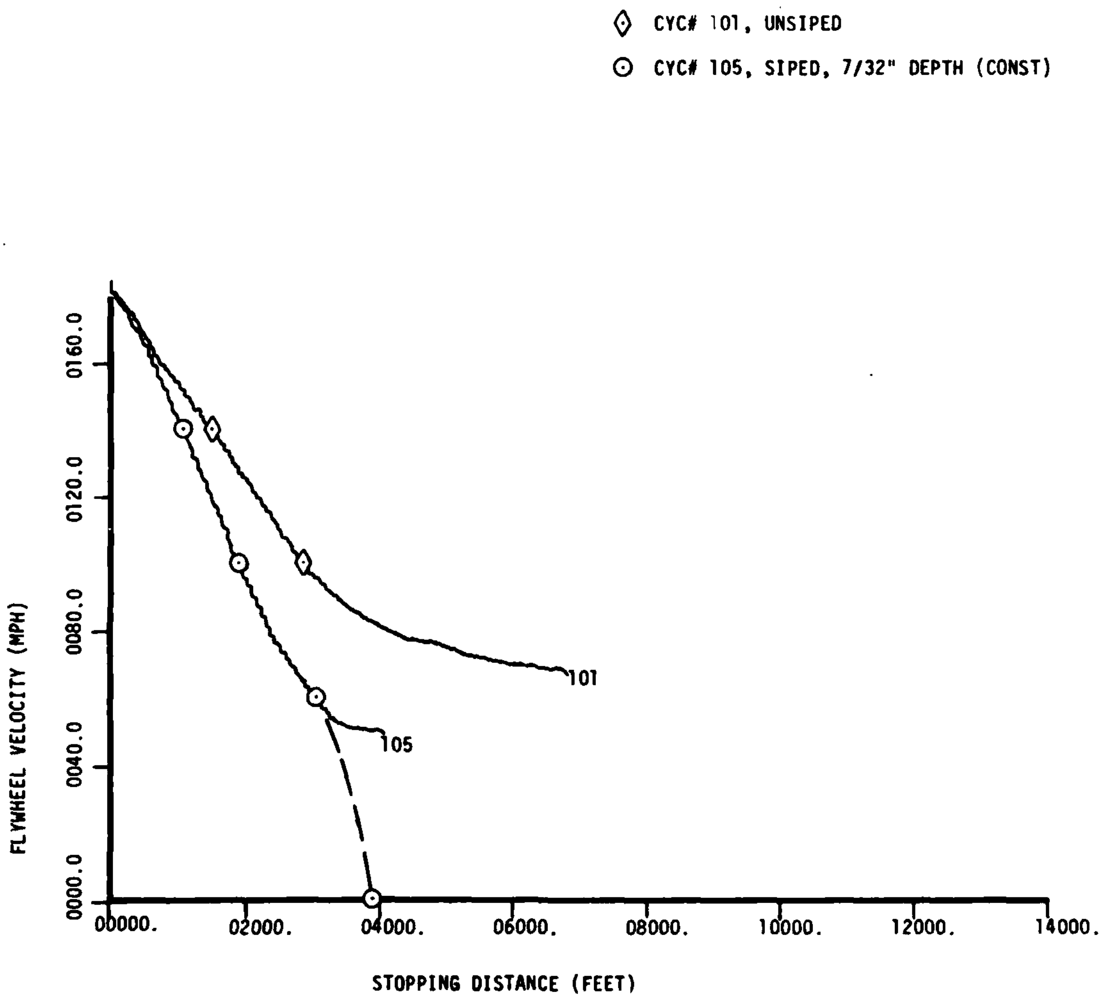


Figure D21. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, 0.5 (GPM) Flow Rate Code Number 1-R-2 Water On After Landing

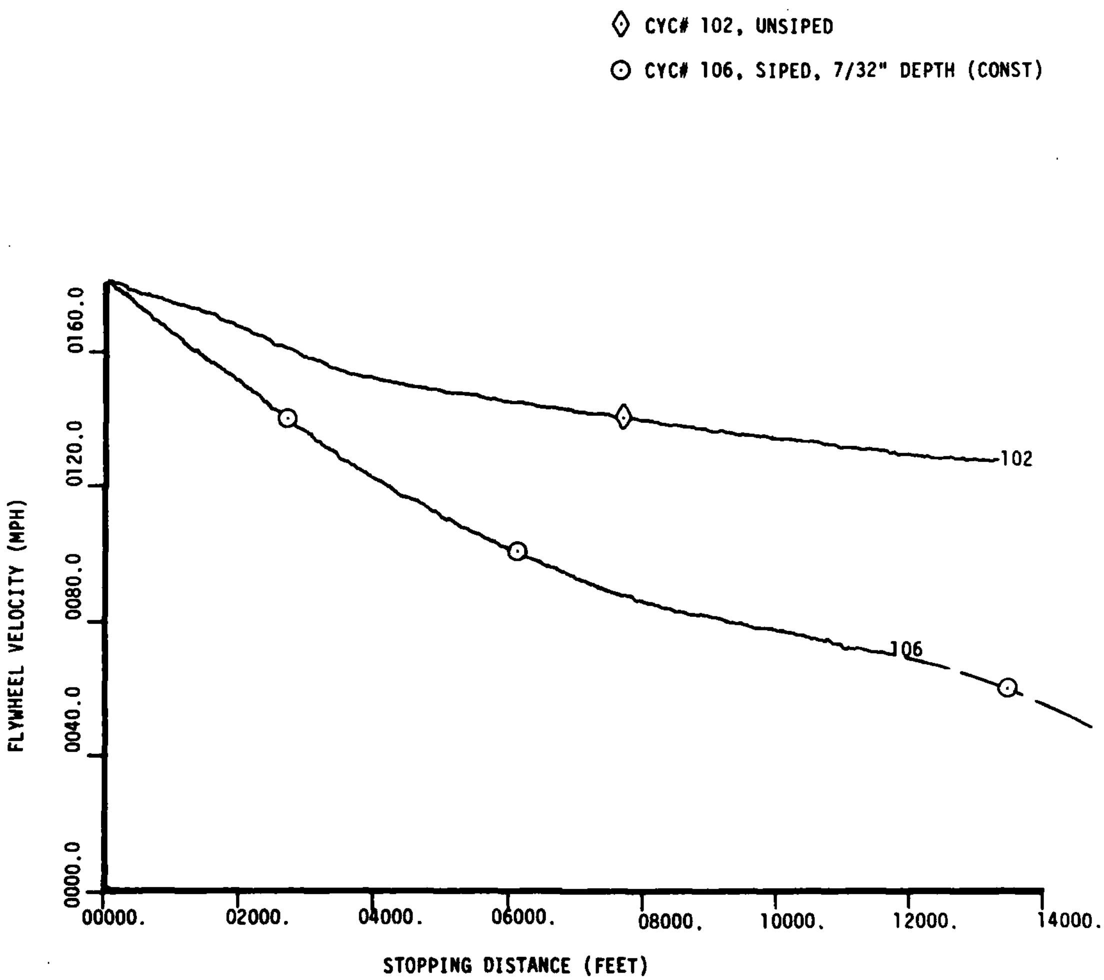


Figure D22. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, 1.0 (GPM) Flow Rate Code Number 1-R-2 Water On After Landing

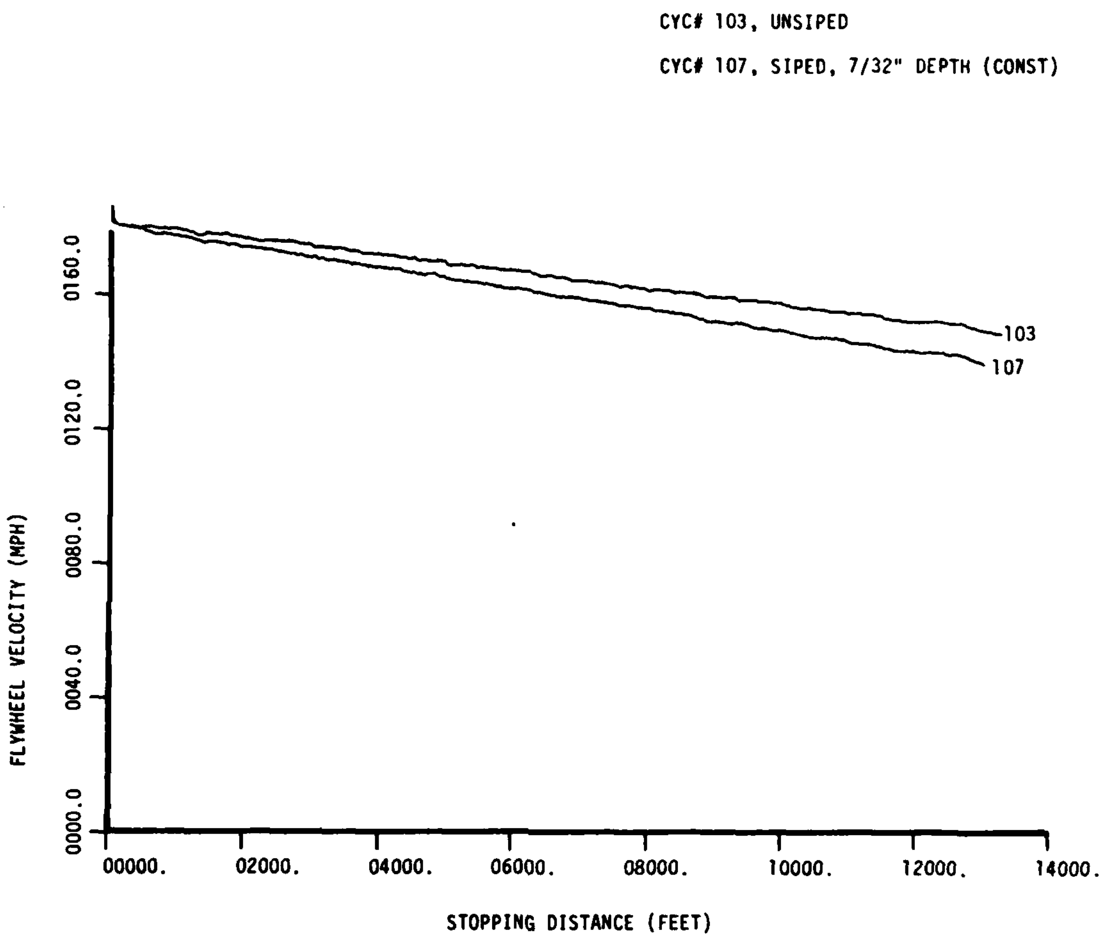


Figure D23. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, 2.0 (GPM) Flow Rate Code Number 1-R-2 Water On After Landing

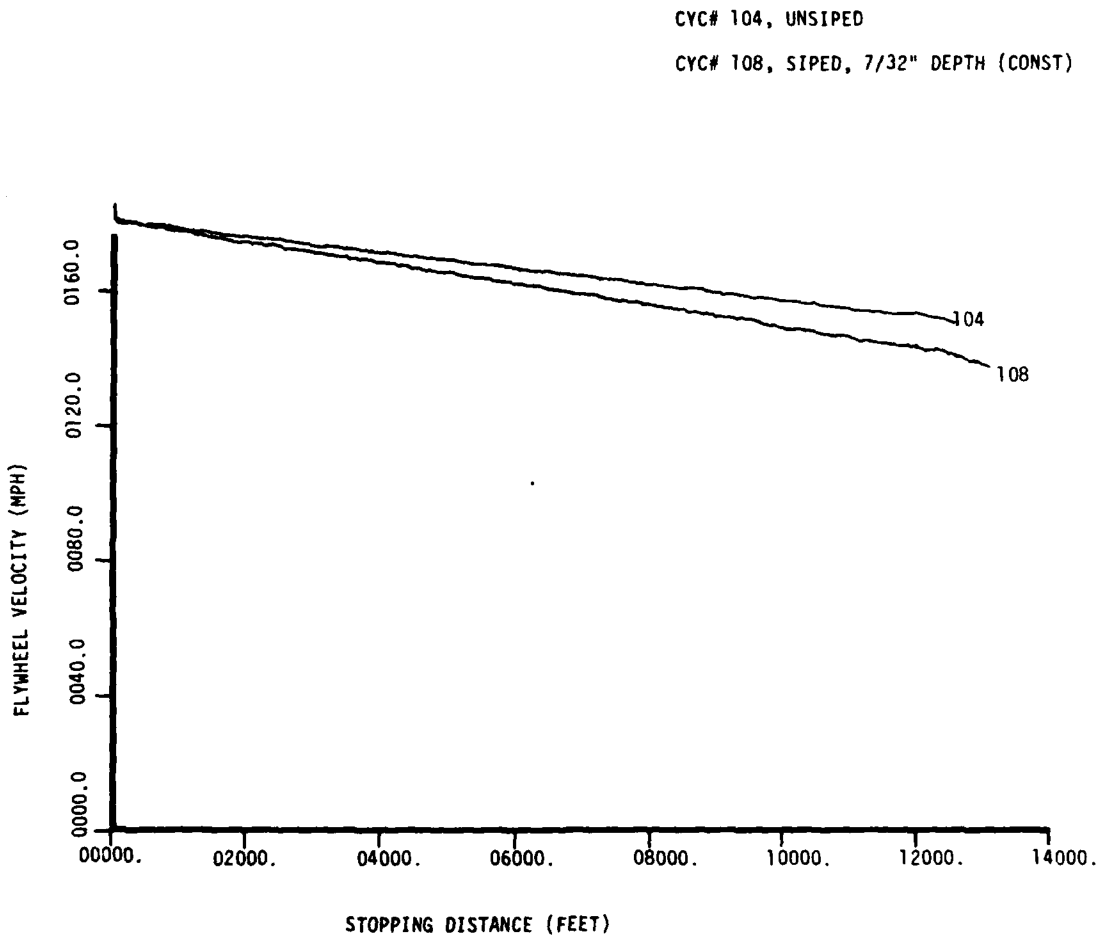


Figure D24. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, 3.0 (GPM) Flow Rate Code Number 1-R-2 Water On After Landing

AD-A112 187 AIR FORCE WRIGHT AERONAUTICAL LABS WRIGHT-PATTERSON AFB OH F/G 1/3
WET TRACTION TESTS - MARCY SIPED TIRE.(U)
FEB 82 P C ULRICH
UNCLASSIFIED AFWAL-TR-81-3068 NL

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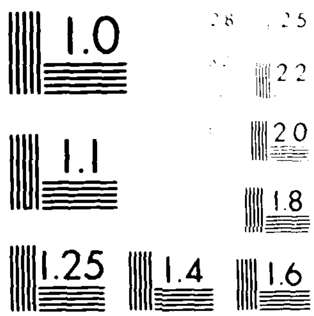

1.0
2.8
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

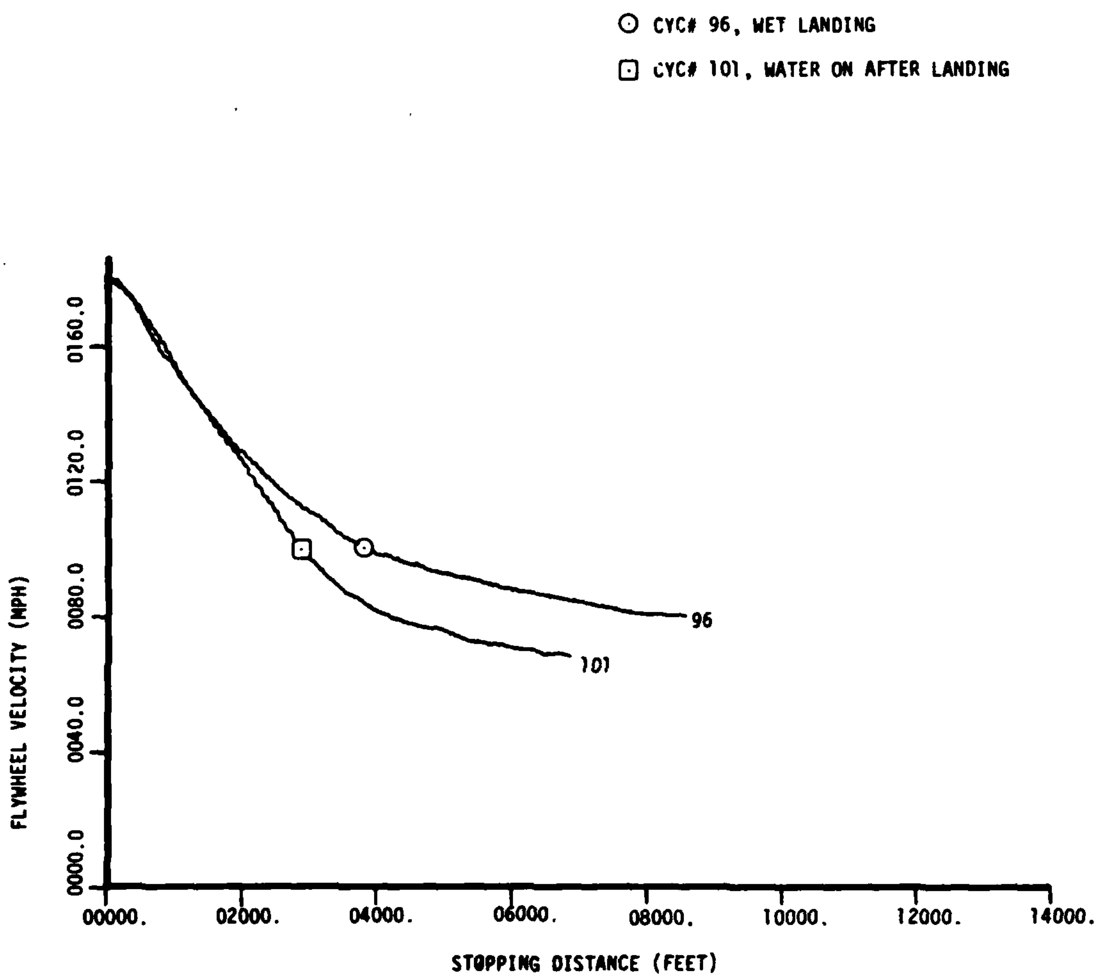


Figure D25. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, 0.5 (GPM) Flow Rate Code Number 1-R-2 Unsiped

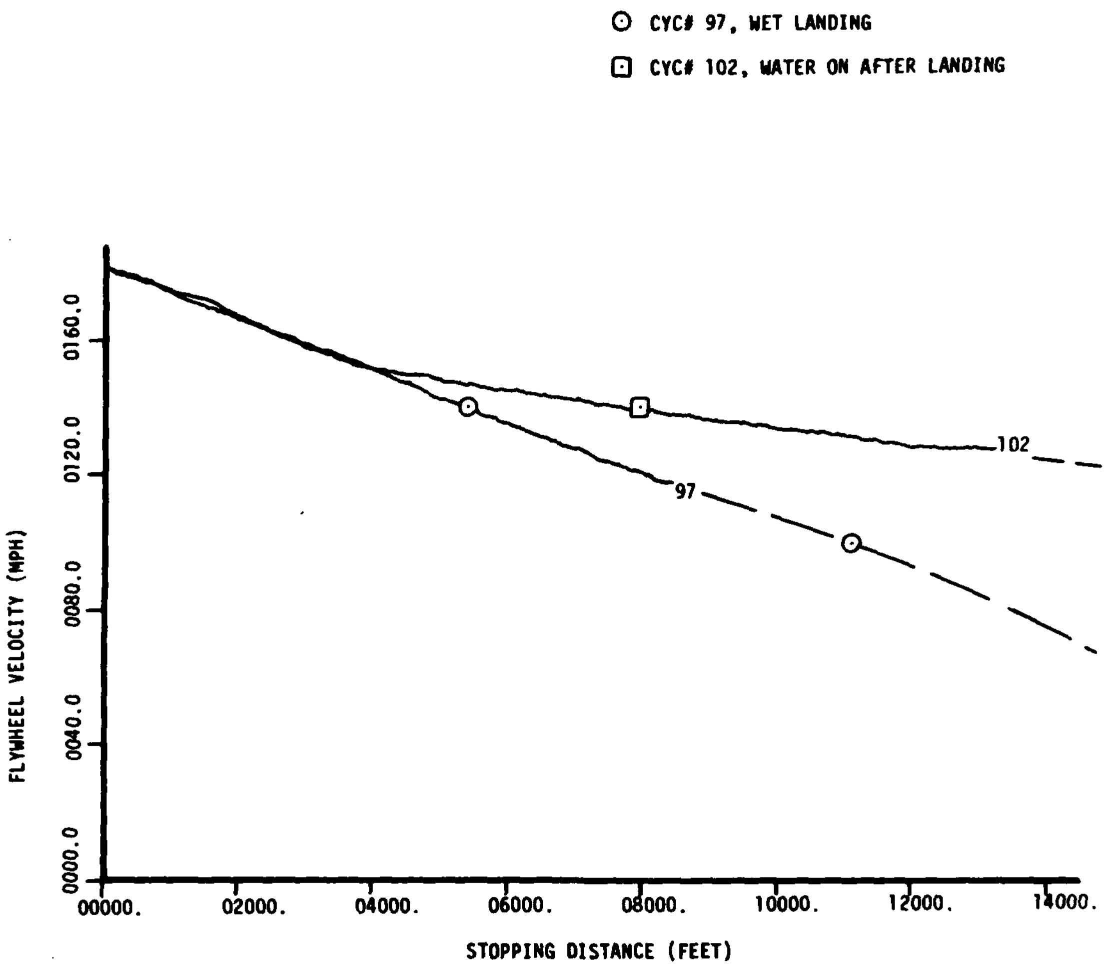


Figure D26. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, 1.0 (GPM) Flow Rate Code Number 1-R-2 Unsiped

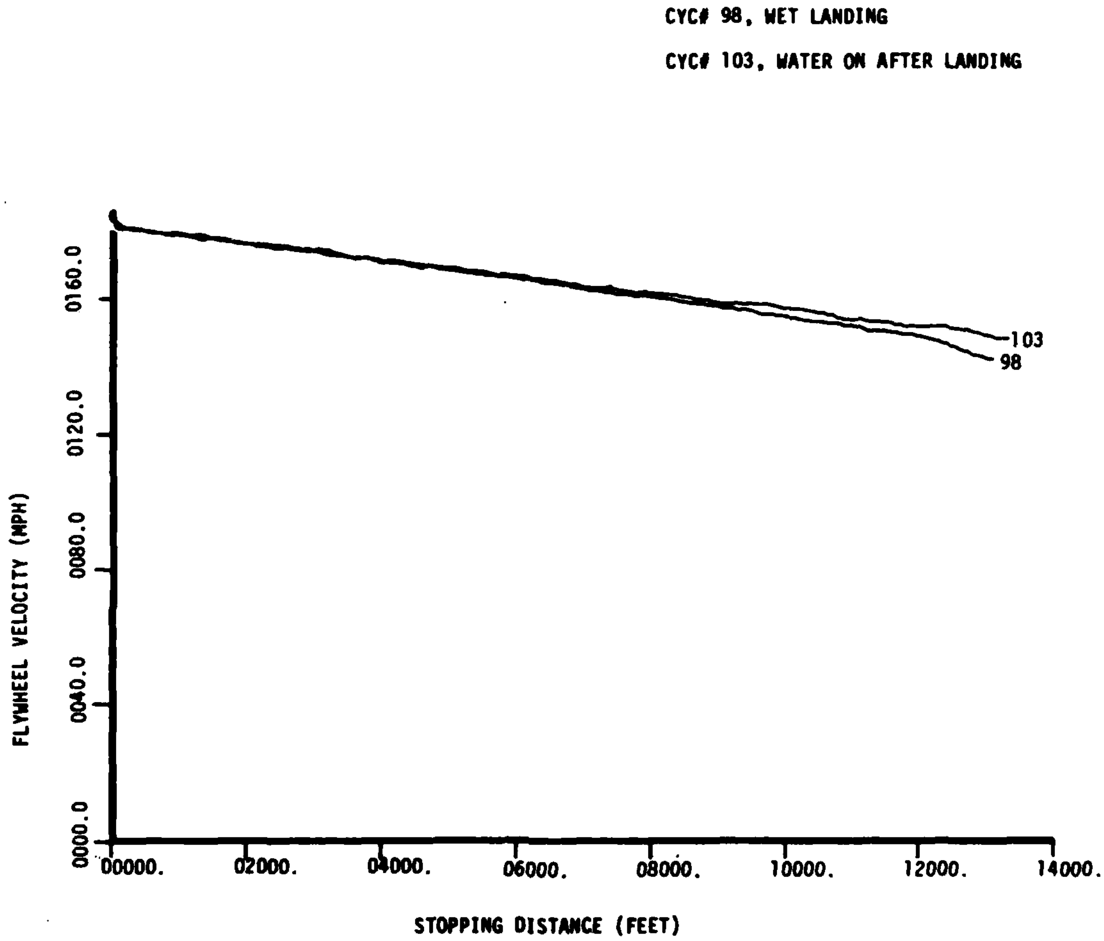


Figure D27. Velocity vs. Brake Distance F-4 MLG, Siped Tire Evaluation 16000 (LBS) Tire Load, 2.0 (GPM) 1o" Rate Code Number 1-R-2 Unsiped

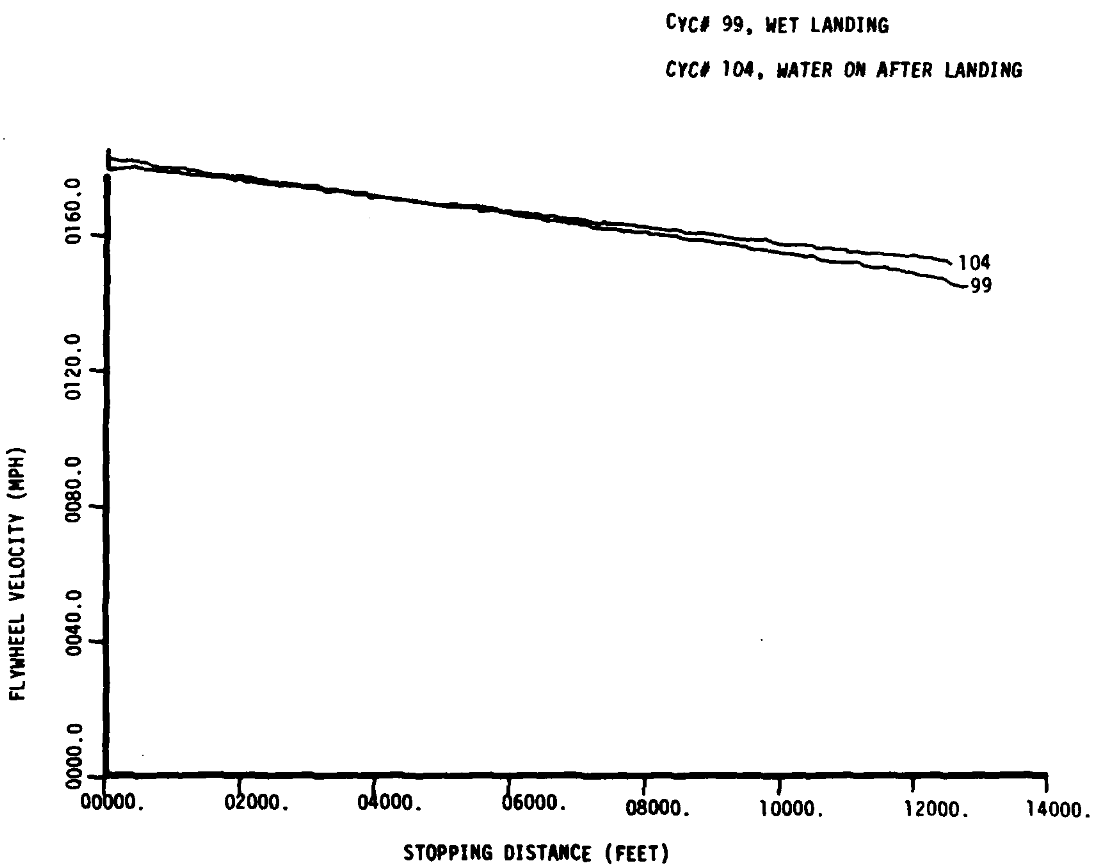


Figure D28. Velocity vs Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, 3.0 (GPM) Flow Rate Code Number 1-R-2 Unsiped

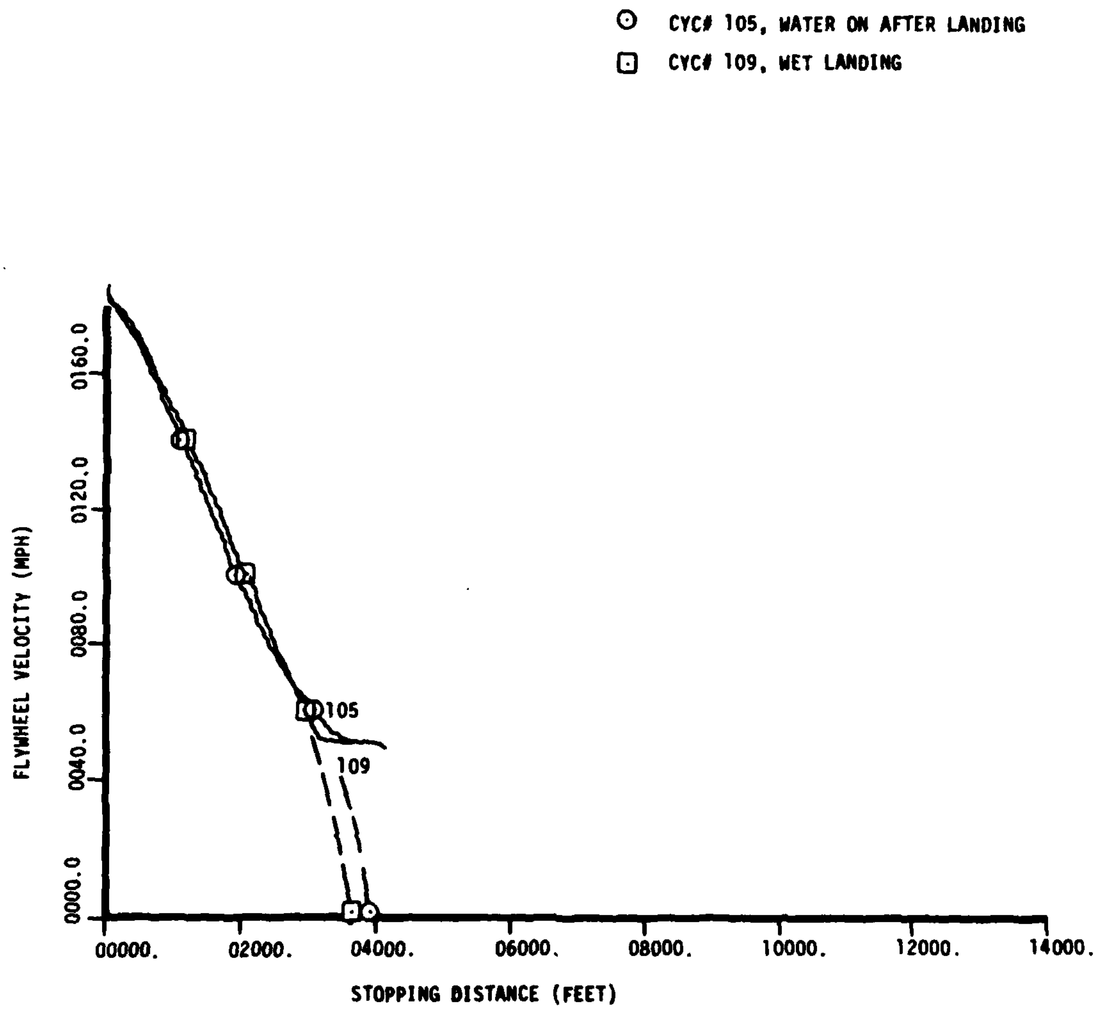


Figure D29. Velocity vs Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, Siped, 7/32" Depth (Const) 0.5 (GPM) Flow Rate, Code Number 1-R-2

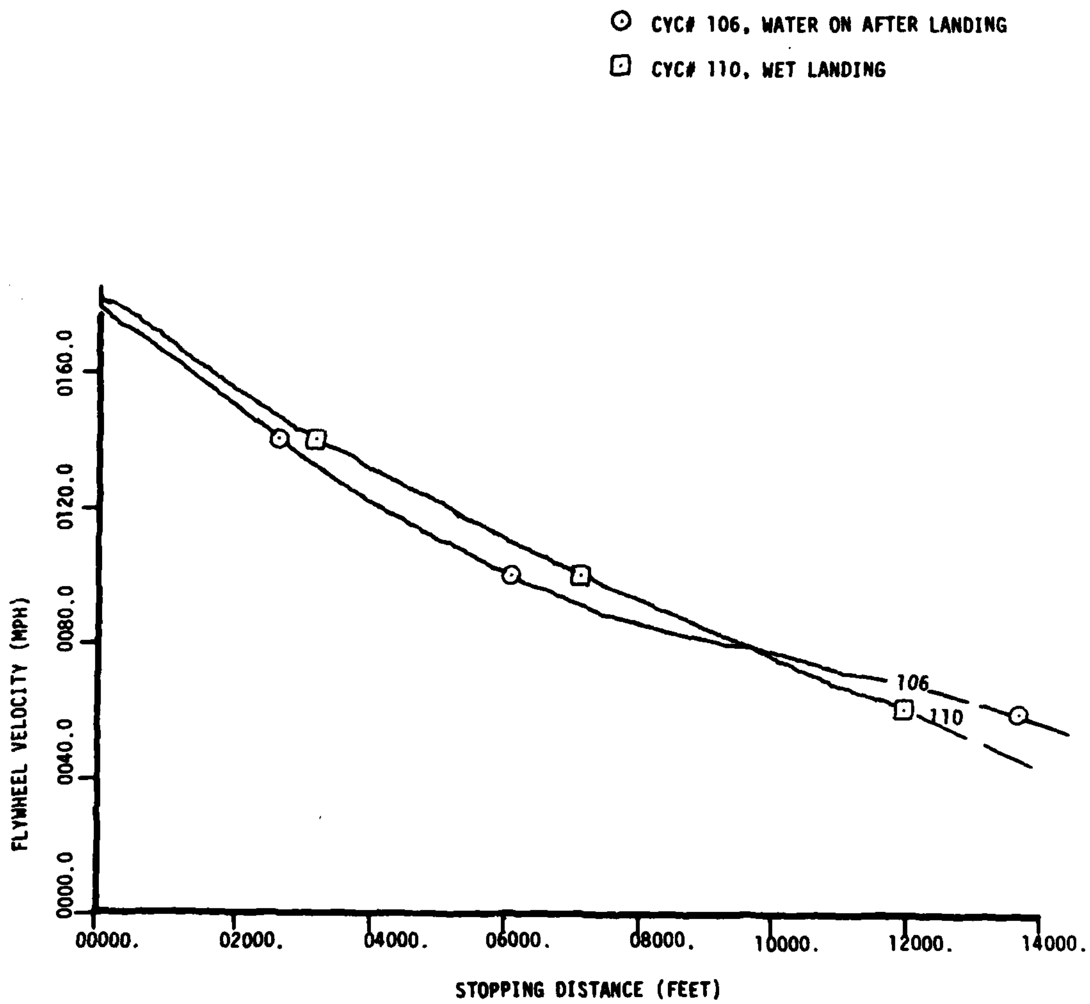


Figure D30. Velocity vs Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, Siped, 7/32" Depth (Const) 1,0 (GPM) Flow Rate, Code Number 1-R-2

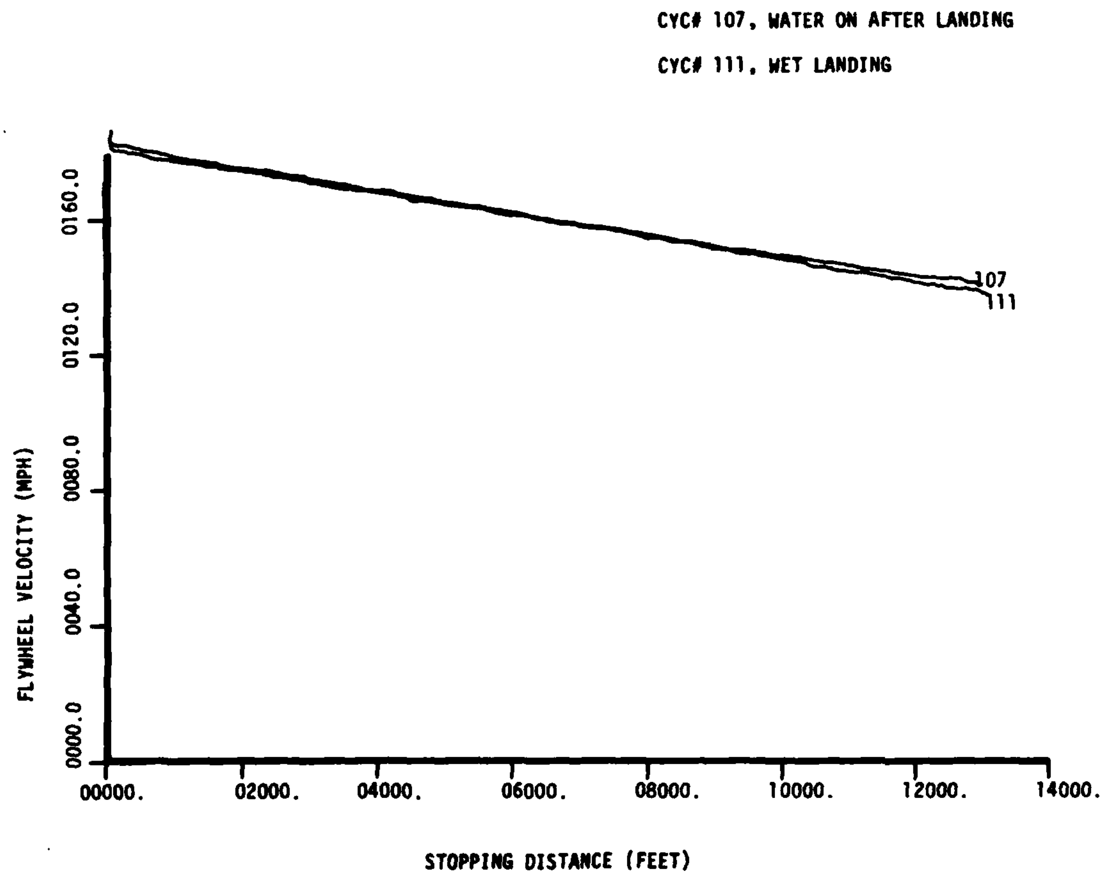


Figure D31. Velocity vs Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, Siped, 7/32" Depth (Const) 2.0 (GPM) Flow Rate, Code Number 1-R-2

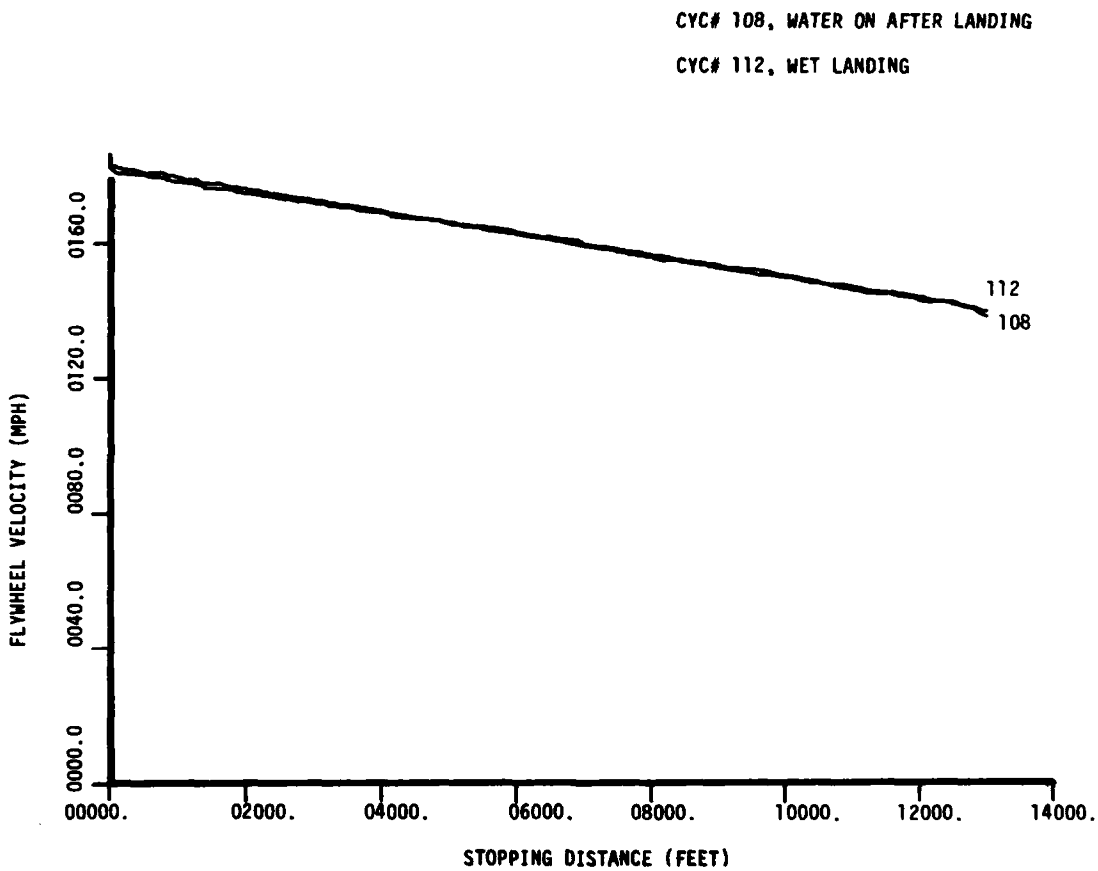


Figure D32. Velocity vs Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, Siped, 7/32" Depth (Const) 3.0 (GPM) Flow Rate, Code Number 1-R-2

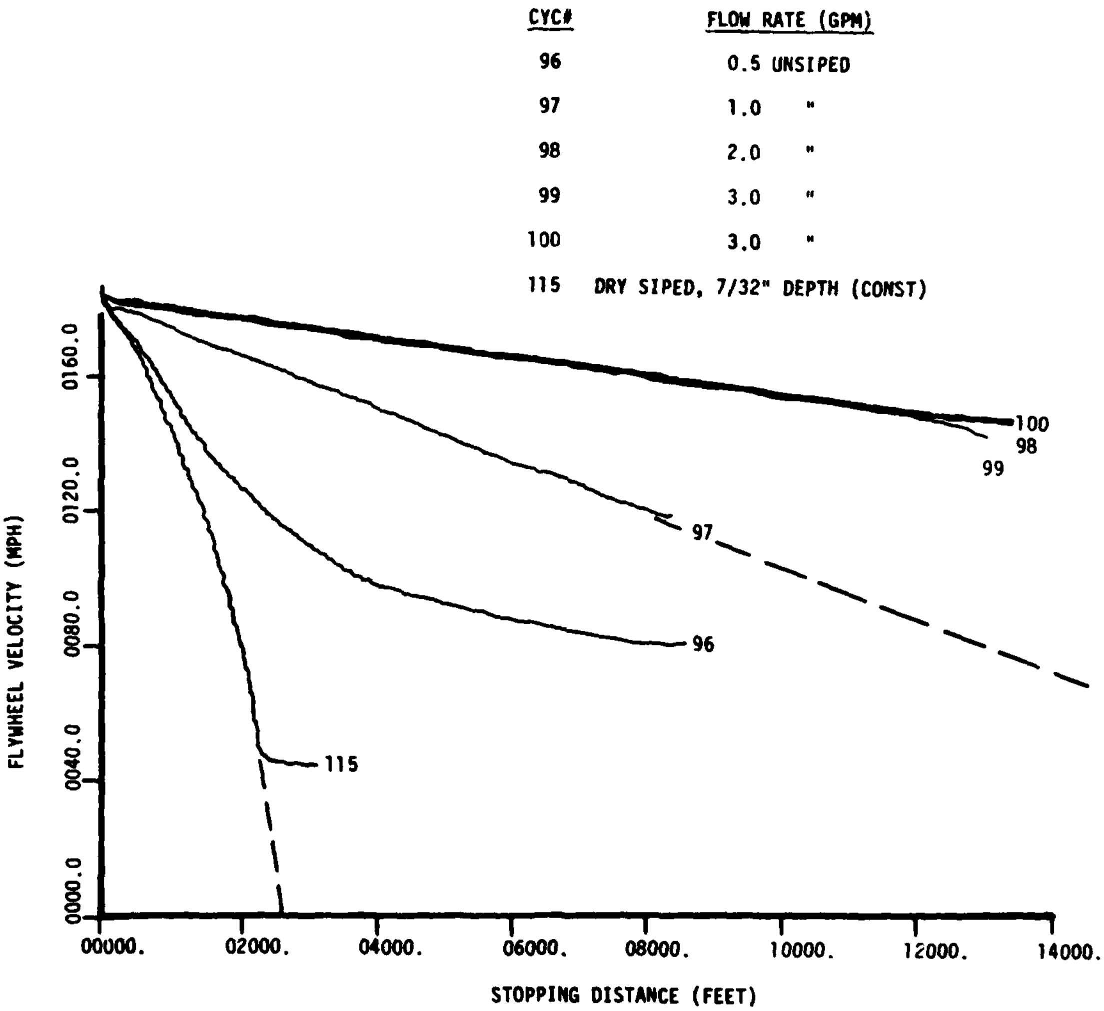


Figure D33. Velocity vs Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, Code Number 1-R-2

CYC#	FLOW RATE (GPM)
101	0.5 UNSIPED
102	1.0 "
103	2.0 "
104	3.0 "
115	DRY SIPED, 7/32 DEPTH (CONST)

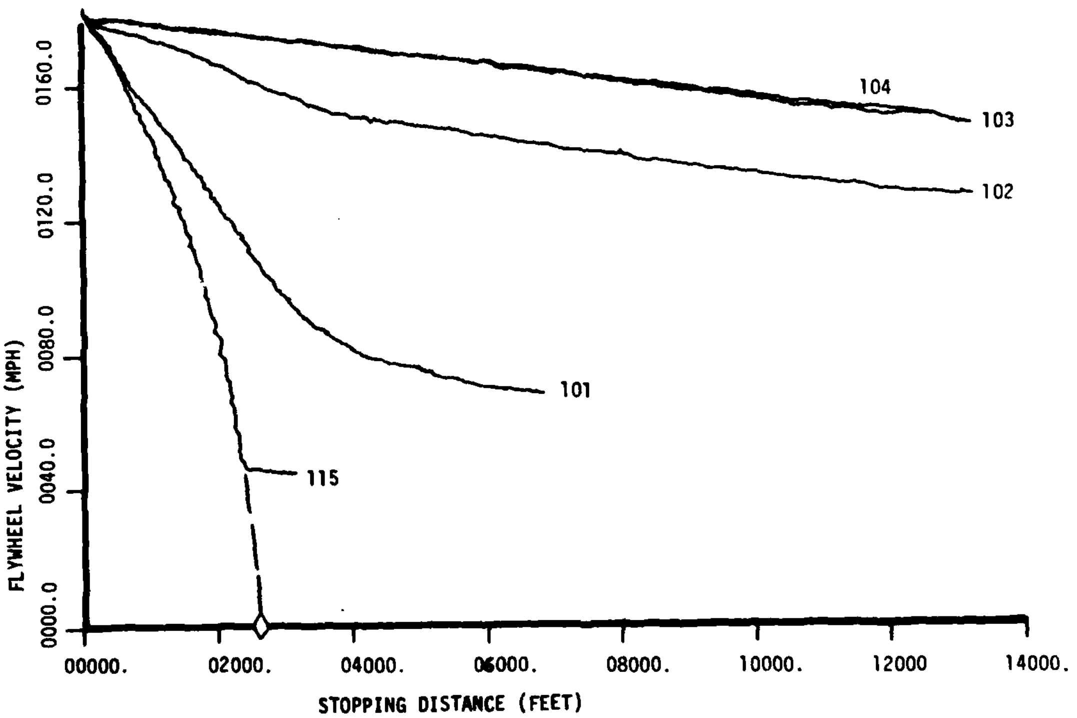


Figure D34. Velocity vs Brake Distance F-4 MLG, Sipe Tire Evaluation 16,000 (LBS) Tire Load, Code Number 1-R-2 Water On After Loading/Before Braking

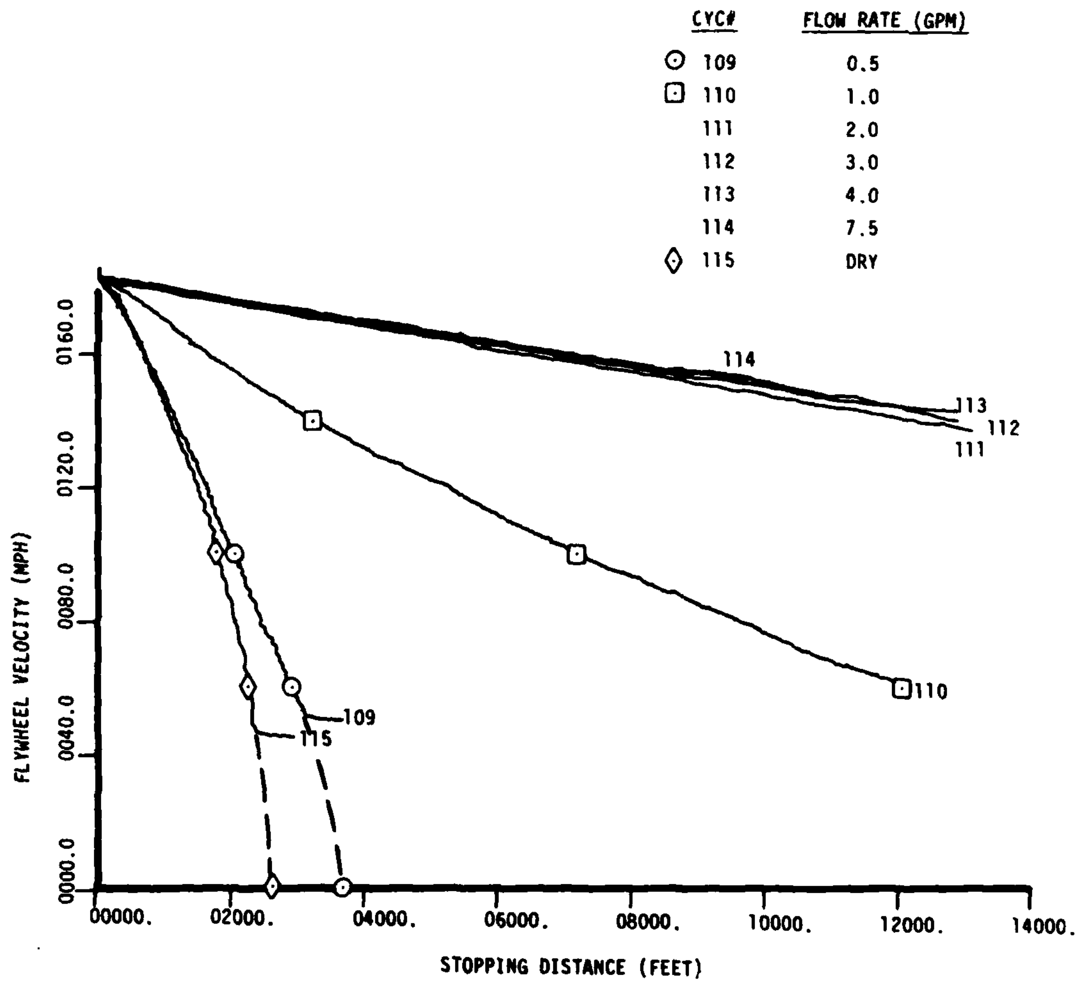


Figure D35. Velocity vs Brake Distance F-4 MLG, Siped Tire Evaluation 16,000 (LBS) Tire Load, Siped, 7/32" Depth (Const) Code Number 1-R-2

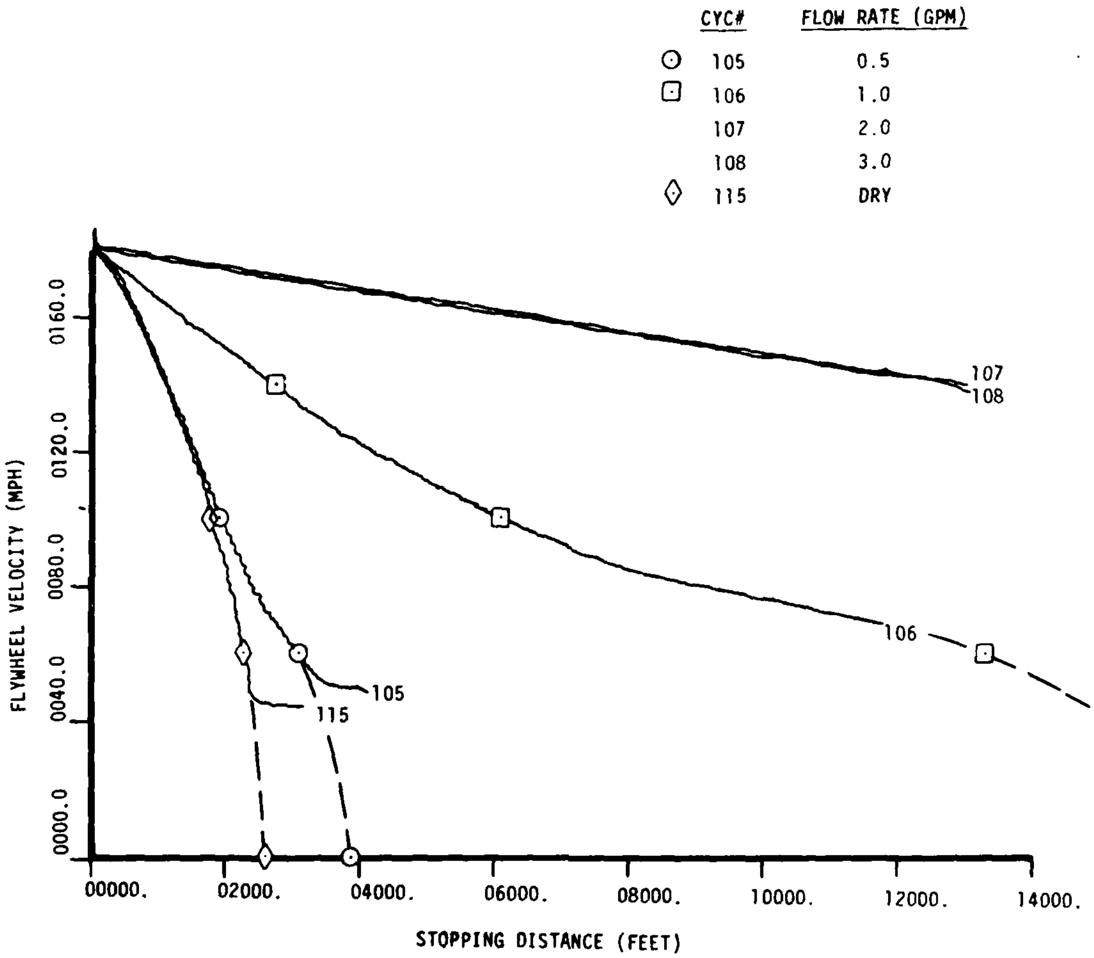
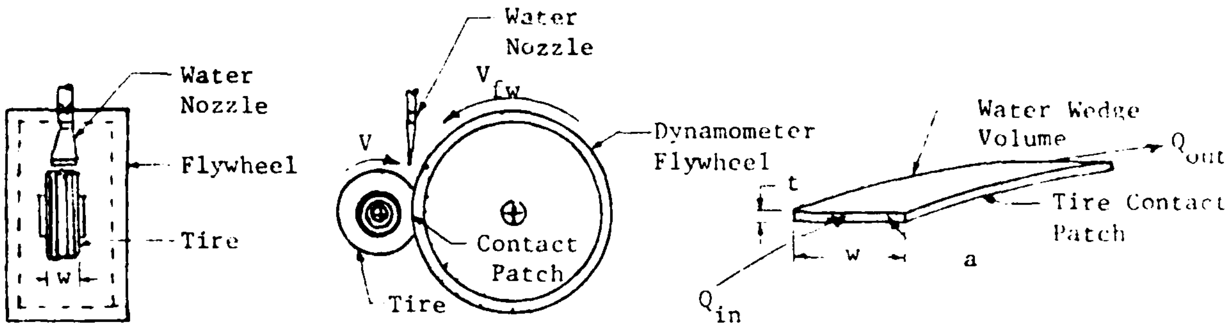


Figure D36. Velocity vs Brake Distance F-4 MLG, Siped Tire Evaluation
16,000 (LBS) Tire Load, Siped, /32" Depth (Const)
Code Number 1-R-2 Water On After Loading/Before Braking

APPENDIX E
CALCULATION SHEET



Calculations For Water Wedge Thickness:

Granted the following calculations and assumptions are not a rigorous attempt at describing the system, the calculations and assumptions made are considered adequate enough to establish trend curves of water wedge thickness as a function of water flow rate, tire contact patch size and dynamometer flywheel speed.

Assumptions:

1. All water passes between tire and flywheel and forms water wedge volume i.e., $Q_{in} = Q_{out}$
2. Water wedge width = tire contact patch width = w = 10 inches (0.833 feet)
3. Water wedge depth = t inches (unknown)
4. Water wedge area = a = w x t
5. Water Velocity, V = tangential velocity of flywheel, V_{fw}
6. Water Flow Rate, Q = V x a
7. Since Q = V x a = V x w x t

$$t = \frac{Q}{V \times w}$$

Calculation 1:

Q = 7.5 gpm = 0.017 feet^3/sec
V = 55 mph = 80.7 feet/sec
w = 10 inches = 0.833 feet

$$t = \frac{Q}{V \times w} = \frac{0.017}{80.7 \times 0.833} = 0.00025 \text{ feet} = 0.003 \text{ inches}$$

Calculation 2:

Q = 7.5 gpm = 0.017 feet^3/sec
V = 140 mph = 205.4 feet/sec
w = 10 inches = 0.833 feet

$$t = \frac{Q}{V \times w} = \frac{0.017}{205.4 \times 0.833} = 0.000094 \text{ feet} = 0.0012 \text{ inches}$$

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